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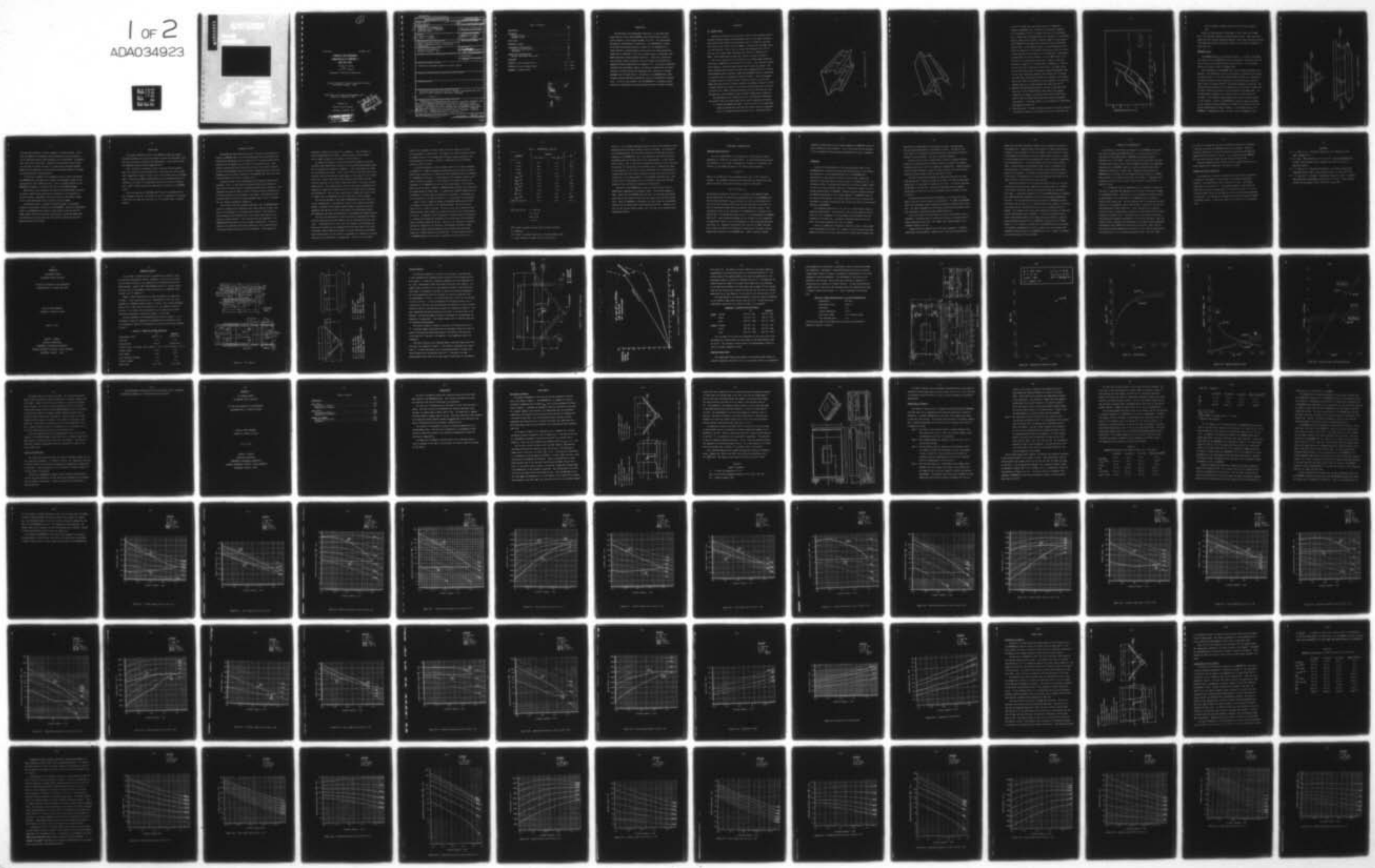

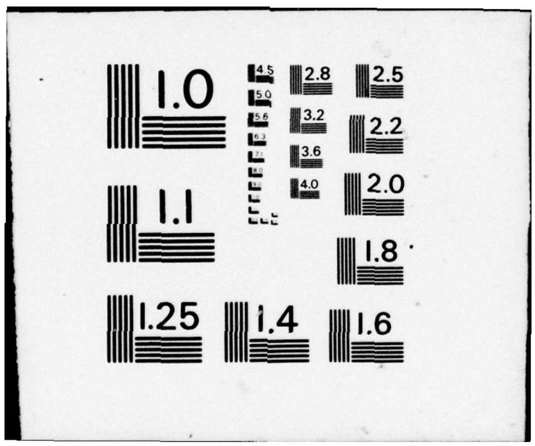
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HYDROSTATIC AND HYDRODYNAMIC CHARACTERISTICS OF "MONOFORM", A NOVEL HULL FORM

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of a 9-month theoretical study of a new small waterplane area hull, called MONOFORM, are reported. The hull is composed of a single cylindrical underwater hull, four V-shaped struts, and a large above water platform. The theoretical results indicate that the MONOFORM is more stable, has less wetted surface, and is structurally more sound than a comparable S^3-SWATH hull. Seakeeping characteristics were not evaluated. A need for further study, including model tests, is indicated.

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INTRODUCTION

The hydrostatic and hydrodynamic properties of a new small waterplane area hull form, called MONOFORM, were studied during a 9-month period (January 1, 1975 through September 30, 1975). The investigation was aimed at establishing the feasibility of the MONOFORM hull concept. It has been found during parametric studies that the MONOFORM hull is indeed feasible, providing smaller wetted surface and larger metacentric height than a comparable S^3 hull with a slight penalty in waterplane area. Higher metacenter implies improved stability, a reduction in wetted surface indicates reduced resistance, while an increase in waterplane area suggests decreased seaworthiness as compared to S^3. The factors influencing resistance and sea-keeping, however, are much more complex than the simple indicators of wetted surface and waterplane area, therefore, an ultimate judgement over the superiority or inferiority of the MONOFORM hull cannot be passed without additional theoretical as well as experimental investigations. It can be said, however, that the MONOFORM is a promising concept and that its usefulness for naval applications should be further evaluated.

BACKGROUND

S^3 - SWATH Concept

During the first half of this decade at least two Navy research centers: the Naval Undersea Research and Development Center in San Diego, California, and the Naval Ship Research and Development Center in Carderock, Maryland, were (and are still today) actively engaged in research and in design studies of a new ship form. The new hull is called "Semi-Submerged Ship" (S^3) by NUC, and it is called "Small Waterplane Area Twin Hull" (SWATH) ship by NSRDC. Both designs have the same basic features as shown in Figure 1.

Most of the buoyant force is provided by two torpedo-shaped underwater hulls and is augmented by the buoyancy of the struts. The relatively slender struts support a wide above-water platform which houses the payload. NUC, after conducting several series of model tests, designed and built a 190-ton "Semi-submerged Stable Platform", named "SSP KALIMANILO" which is being used as a support vessel for underwater research in Hawaii. NUC is now engaged in design studies of a 500-ton and of a 3000-ton version of the S^3 hull. NSRDC performed more basic research and model experiments on several versions of SWATH than NUC did, however, they did not build anything near the size of the 190-ton SSP. NSRDC's thinking presently favors the one strut per side configuration, which resembles Litton's "TRISEC" design shown in Figure 2.

The advantages of the S^3-SWATH hulls over a conventional displacement type surface ship of the same weight can be briefly summarized as follows:

1) Reduced wave-making resistance. Since the bulk of the displacement volume is removed well below the free surface, waves are generated only by the slender surface-piercing struts. The wetted surface

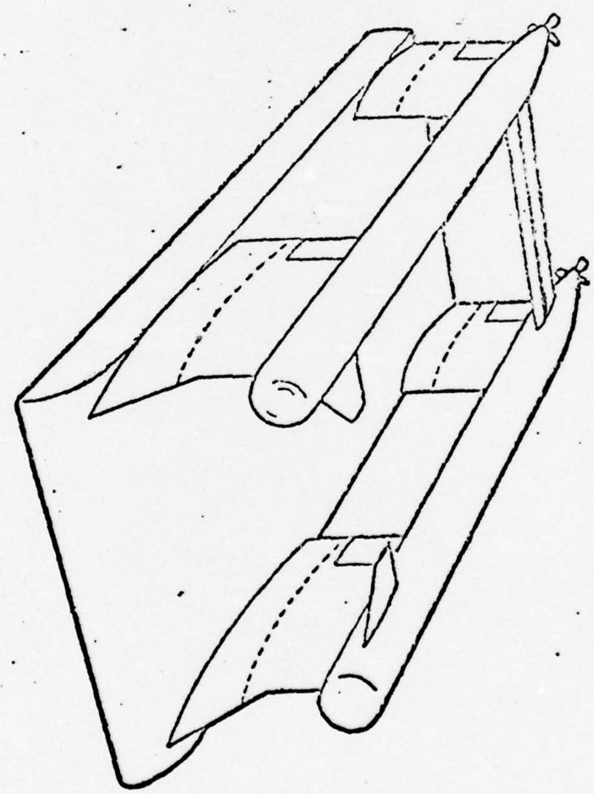

Figure 1. NUC's Semi Submerged Ship (S^3)

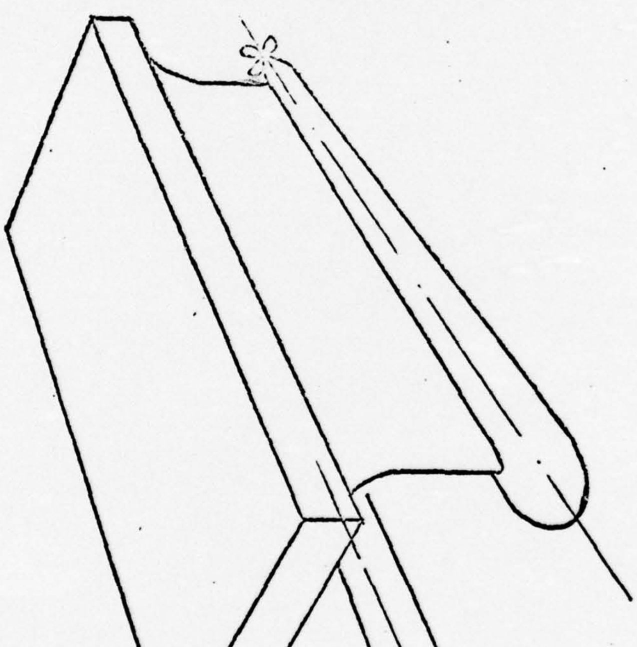

Figure 2. Litton's TRISEC design

of the S^3 is larger than the wetted surface of a comparable ordinary displacement hull, therefore, the frictional component of the resistance of the S^3 is larger than that of a displacement hull. Because the wave-making part of the resistance of conventional ships is rather small at small to moderate speeds, at these speeds the S^3-SWATH hull has larger total resistance than a conventional surface ship. At high speeds, however, the wave-making part dominates the resistance of the ordinary surface ship, while it is still a small fraction of the resistance of the SWATH hull. Consequently, at high speeds, the total resistance of the S^3-SWATH ship is less than that of a conventional surface ship. Figure 3, taken from reference 1, compares the estimated power requirement of a 3000-ton S^3 hull with that of other type surface ships. The figure shows that below 25 knots speed the destroyer (surface-displacement ship) has the least resistance, between 25 and 50 knots the S^3 requires the least power, while above 50 knots the resistance of the Surface Effect Ship (SES) is the smallest of those compared. The hydrofoil supported ship at all speeds requires more power than the S^3.

2) Improved seakeeping characteristics. Because of the small water-plane area of the S^3-SWATH design, these hulls do not respond strongly to the seaway, thus they provide much more stable platforms at high sea states than conventional surface displacement type ships do. A secondary benefit is the capability of maintaining high speeds in stormy seas.

3) Large deck area. The wide transverse spacing of the struts (required for stability) results in an extremely wide deck, a much wider one

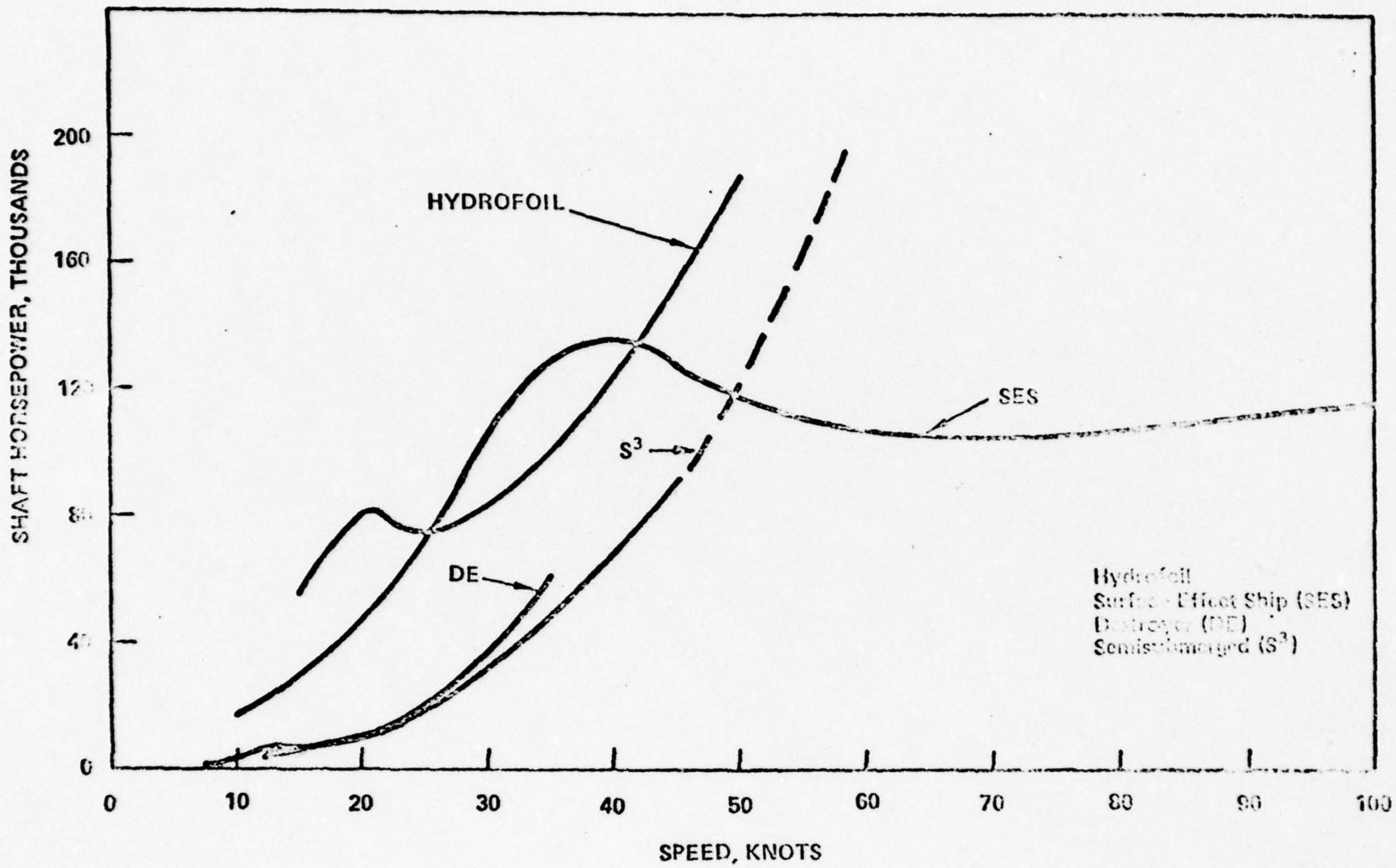

Figure 3. Power Comparison for Four Types of 3000-Ton Surface Ships

than the decks of ordinary surface ships of the same displacement.

Mainly the characteristics listed under 2) and 3) make the S^3-SWATH hull a very desirable platform for military applications. Small ships with large deck areas and good seakeeping qualities could perform military functions (like supporting aircraft operations) which until now could be performed by large ships only.

MONOFORM Concept

The MONOFORM design is illustrated in Figure 4. It differs from SWATH-type ships in that the MONOFORM has only one underwater cylindrical hull and that its struts are V-shaped instead of being vertical. The above-water platform is similar to that of S^3-SWATH ships.

Three advantages of the MONOFORM hull over the SWATH configuration are apparent. The elimination of one of the underwater cylindrical hulls reduces the wetted surface. If all other factors remain constant, the resistance of the ship is reduced in direct proportion to the wetted surface reduction, which could be as high as 15%-20%. The second advantage is structural. The closed structure achieved by the V-shaped struts is inherently stronger than the open, inverted U structure of the twin hulled S^3 and SWATH ships. For the same overall strength, the V-structure will be lighter than the U-structure. This potential weight saving could be used to bolster payload or fuel capacity. Finally, the MONOFORM hull does not require horizontal control surfaces which are necessary for dynamic pitch control of the twin hulled S^3-SWATH ships as shown on Figure 1. The V-shaped struts of the MONOFORM, if equipped with flaps, can exert forces and moments in the

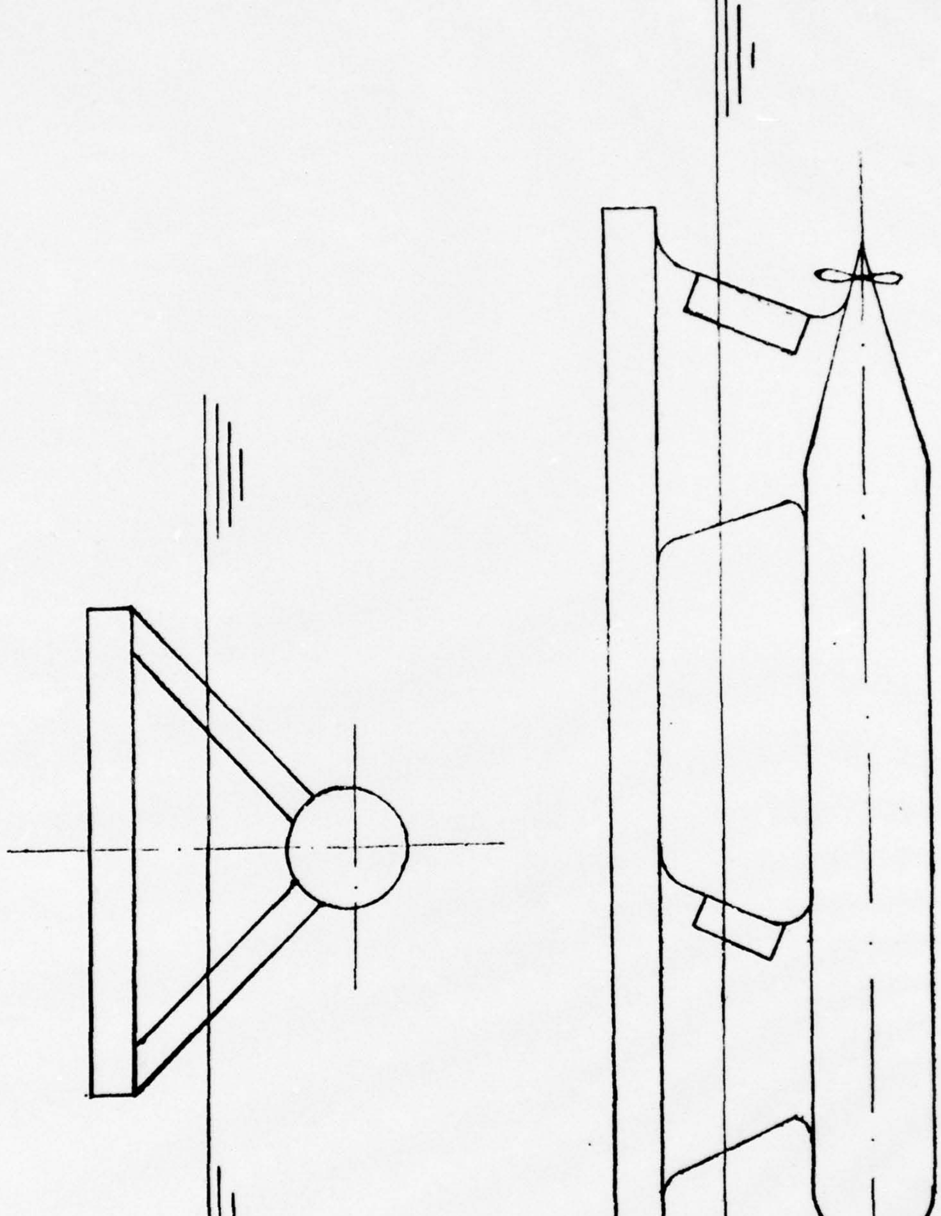

Figure 4. VPI & SU's MONOFORM ship

vertical plane similarly to control surfaces of V-tailed aircraft. Therefore, the addition of horizontal control surfaces will not be necessary, and the additional drag of these appendices will be eliminated. Coordinated turns could also be performed. Although the flap-produced control forces will pass near the center of gravity, it appears that only small heeling moments will be generated in turns and that these moments might be countered by using differential flap deflections.

In the event of damage to the underwater portion of one of the struts, the MONOFORM hull would experience a smaller heeling moment (caused by the entering water) than a SWATH hull would. Thus, the damage stability of the MONOFORM hull appears to be superior to that of the S^3-SWATH designs.

Human access to the underwater hull would be provided through the struts by means of ladders which would have an inclination to the horizontal of around 45 degrees. Depending on the size of the ship, this might or might not be a more comfortable access route than the one on SWATH.

As mentioned earlier, a saving in structural weight is anticipated because of the V-shaped, closed form of the MONOFORM. Should the hydrodynamic loads on the MONOFORM struts require so much heavier structures that the weight saving could not be realized, the shifting of structural weight from the platform to the struts will lower the center of gravity and thus will improve stability even further.

STUDY TASKS

The 9-month theoretical study of the MONOFORM concept was aimed at ascertaining whether the concept was feasible, whether the advantages cited were real, and whether there were any disadvantages. Three specific tasks were assigned which are briefly summarized here.

Task 1 called for a parametric study to optimize the hull geometry, task 2 was directed to the hydrodynamics of flow between the struts, while task 3 compared the results of tasks 1 and 2 with available data on S^3-SWATH ships. Since data on NSRDC's SWATH designs are not published and were not available to the study, all comparisons were based on various S^3 designs only. (NUC's relevant reports were made easily accessible to the MONOFORM study.)

Since the comparison of MONOFORM and S^3 data were performed step by step throughout the study, the results of task 3 are embedded in the results of the first two tasks and, therefore, are not presented under a separate heading.

PARAMETRIC STUDIES

The parametric study indicated that any S^3 design can be matched by a variety of MONOFORM hulls (of the same displacement and of essentially the same platform dimensions) which are superior to S^3 in wetted surface and in stability for the expense of an increase in the waterplane area. Since without a detailed structural design the location of the center of gravity could not be determined accurately, stability computations were based on the assumption that the center of gravity of the MONOFORM hull lies at the same relative height as the center of gravity of S^3.

During the course of the investigation three parametric studies were performed. First, a crude stability-oriented analysis was completed to show that the inclined struts will provide sufficient static stability. The comparison was based on model A of NUC's S^3 design, because information on the 190-ton SSP was not yet available to the study. This analysis was described in detail in the first interim progress report, which is included here for reference purposes as Appendix A.

The results of the first analysis indicated, that the MONOFORM model chosen for comparison was indeed much more stable than the S^3 model, however, for the expense of an increased wetted surface. The increase in wetted surface was in contradiction to the original expectation of a reduction in wetted surface. It was concluded that the dimensions of the MONOFORM model used were far from an optimum configuration. To gain insight into the influence of the main dimensions on hull characteristics, curves were plotted as functions of hull parameters. These graphs are

presented in Figures A-6 through A-9 of Appendix A. The usefulness of these investigations were, however, limited because the hull geometry was too tightly coupled to the geometry of the S^3 model A.

To remedy the situation a second, more flexible parametric study was initiated, whose results were presented in the second interim progress report and are included for reference in Appendix B. This investigation was based on two different strut types. Strut A was cylindrical with lenticular cross-sections, and with trailing and leading edges at right angles to the cylinder center line. Strut B had variable cross-sections (lenticular above the waterline changing to blunt nosed, stream-lined shape at the base), and with tapered struts. Hull characteristics for the A-type strut configuration are presented in Figures B-2 through B-24, and for the B-type struts in Figures B-26 through B-47. For the A-type struts, which resemble the struts of the S^3 design, lines of comparison with the 190-ton SSP are also included.

The results indicated a wide range of MONOFORM hulls, with either A or B strut configurations, to be superior to SSP in both stability and wetted surface. Reviewers of the progress report, however, pointed out that the comparison with SSP was not quite clear because the relationship between deck dimensions and other characteristics, as presented, was somewhat obscure.

The use of the tapered strut (type B) resulted in improved hull characteristics (stability and wetted surface) over the characteristics with strut type A. Investigations of a strut type C with dynamic lift producing capability were initiated but not completed within the time limit of the study. Preliminary results showed that dynamic lift would reduce draft and thereby wetted surface which, in turn, would be accompanied by a reduction in viscous drag and by the introduction of induced drag. There will be an optimum

dynamic lift, dependent on vehicle speed, which will result in the least total resistance at a given speed. The dynamic lift could be produced either by cambered struts, or by incorporation of movable control surfaces at the trailing edges of the struts. Probably a combination of the two methods would give the best result.

To avoid the ambiguity of using "design charts" such as those presented in Appendix B, a computer program was developed which, upon input of certain desired hull characteristics, computes the major dimensions and hull parameters of a MONOFORM ship directly. The development of the computer program is presented in detail in Appendix C. This program can be used effectively for comparison of the MONOFORM hull with any twin hulled design. (The computer model can also be used to optimize a MONOFORM design, however, what constitutes an optimum design is rather vague. It appears that "optimum" depends more on the mission of the ship than on anything else, therefore, a ship design can not be optimized in the absolute sense; i.e., to be optimal for any mission.)

Table 1 shows a comparison between two MONOFORM designs and NUC's SSP. The designs are constrained to the same displacement (190 tons) and deck width (45 ft) as those of the SSP. The use of strut type B resulted in the smallest wetted surface (4010 sq ft) which is only 83% of the wetted surface of the SSP. In addition to the 17% decrease in wetted surface, the drag will be reduced also through the elimination of the form drag of the horizontal control surfaces present on the SSP. There are a 13% increase in transverse metacentric height and a 37% increase in longitudinal metacentric height. The one foot larger cylinder diameter would accommodate the power plant easier for a slight penalty in increased drag. The major penalty paid by the MONOFORM design is an increase in waterplane area from 230 sq ft to

Table 1. MONOFORM-SSP Comparison

PARAMETER	MONOFORM		SSP
	Strut Type: A	Strut Type: B	
B (ft)	45.0	45.0	45.0
L (ft)	68.6	75.6	74.0
D (ft)	6.0	7.5	6.5
β (deg)	48.3	44.3	---
L_{SWL} (ft)	29.33	29.33	24.0
T_{SWL} (ft)	4.4	4.4	3.6
Gap_{WL} (%)	33.9	31.0	~100
A_{WP} (ft^2)	517	480	230
$\overline{GM}$ (ft)	4.77	5.10	4.5
$\overline{GM}_L$ (ft)	25.8	21.5	15.7
S_{WET} (ft^2)	4270	4010	4830
Draft to Keel (ft)	14.1	17.6	15.3

$\overline{RG} = 0.71\ (H + F)$ $\Delta = 190$ tons

$F = 6.0$ ft

$H/D = 1.85$

$t = 0.15$

$\overline{RG}$ = center of gravity location above cylinder centerline

F = freeboard

H/D = draft of cylinder centerline to cylinder diameter ratio

t = strut thickness to length ratio at the waterline

480 sq ft. The increased waterplane area will result in an increase in wave-making resistance and might adversely affect sea-keeping. As discussed in the following section, the theoretical predictions of resistance and sea-keeping of the MONOFORM hull are of such complexity that they could not be performed during the 9 months span of this investigation. It can be estimated, however, that the increase in wave-making resistance will be less than the decrease in viscous drag, thus providing a hull of reduced total drag. For sea-keeping, the wave excited forces and moments will increase with increased waterplane area, however, damping and added mass effects will also increase due to the unique geometry of the MONOFORM underwater hull. Thus, the net effect on sea-keeping can not be estimated without more detailed theoretical and, preferably, experimental investigations.

The draft of the MONOFORM may or may not be greater than that of a SWATH design, depending on the geometry chosen. The previous example in Table 1 shows that the MONOFORM ship with type A struts would have smaller draft than the SSP, while the ship with the B-type struts will have larger draft. While the MONOFORM is stationary, its draft cannot be substantially reduced from the design value without impairing stability. Underway, however, if the V-struts produce dynamic lift, the drag can be reduced without decreasing stability.

HYDRODYNAMIC CONSIDERATIONS

Resistance Characteristics

As a first approximation, the resistance of a ship reduces in direct proportion to a reduction in wetted surface. In naval architectural practice, the resistance, R, of a ship is expressed as a product of a resistance coefficient, C_R, the dynamic pressure $\rho/2\ V^2$, and the wetted surface S.

$$R = C_R \frac{\rho}{2} V^2 S$$

where ρ is the density of the surrounding water, and V is the velocity of the ship. The resistance coefficient may conveniently be divided into three parts; frictional, form, and wave-making resistance coefficients.

$$C_R = C_f + C_{form} + C_w$$

The frictional resistance coefficient, C_f, depends on the Reynolds number and has essentially the same value for comparable size S^3 and MONOFORM hulls. The form drag coefficient, C_{form}, includes the effect of flow separation at the tail of the cylindrical hull and at the trailing edges of the struts, as well as interference between struts and between struts and cylinder. This interference effect on the resistance of the MONOFORM hull is unknown at the present time. The interference might be more or less advantageous for MONOFORM than for S^3. Quick theoretical methods are not available for the computation of interference effects or for the determination of the wave-making resistance coefficient, C_w. Repeated consultations with scientists at NSRDC confirmed that no short cuts exist for theoretically estimating the resistance and sea-keeping characteristics of the MONOFORM hull. NSRDC's elaborate computer

programs for SWATH ships are not readily adaptable to MONOFORM, because of basic differences in hull geometry. This is one reason why the extension of the investigation into experimental determination of drag is suggested.

Seakeeping

During the oral presentation of the second progress report of the MONOFORM project, concern from several ONR representatives in the audience was expressed as to the seakeeping qualities of the MONOFORM hull. Specifically, it was pointed out that the V-struts might respond more adversely to beam seas than the vertical struts of S^3-SWATH hulls do. All subsequent efforts, including consultation with scientists at NSRDC, failed to turn up an (even relatively) easy way to theoretically predict the seakeeping characteristics of MONOFORM. Elaborate computer programs developed for SWATH investigations are not readily adaptable to MONOFORM because of the unique V-strut design. All previous theoretical work was concentrated exclusively on ordinary displacement type surface ships which are drastically different from MONOFORM.

The seakeeping characteristic of a ship is a property which cannot be expressed quantitatively. Qualitatively, a ship is more seaworthy than an other one if its responses to the same seaway are more moderate than the responses of the other ship. In general, seakeeping improves with size, thus a CVA is more seaworthy than a DD, for example.

A ship in a seaway has six degrees of freedom of motion. Waves induce forces and moments on the ship. As a response to these exciting forces and moments the motion of the ship deviates from a constant speed straight line

motion which it would exhibit in the absence of waves. The deviations from the undisturbed motion are oscillatory in nature. The ship is said to be stable if the induced oscillations decay with time without corrective actions of control surfaces. The ship is unstable otherwise.

From the point of view of seaworthiness (comfort of personnel and usefulness as a military platform) surging (fore and aft motion) and swaying (transverse motion) of a ship in a seaway are insignificant. Yawing (turning) is also of small importance, except for ships unstable in yaw which require constant corrective rudder action to keep them on course.

The other three motions determine *the seakeeping qualities* of a ship. These motions are: heaving, pitching, and rolling. All three motions might appear alone, or they might be coupled to each other. The factors affecting the motions of the ship are: exciting and restoring forces or moments, virtual mass or inertia of the hull, and damping forces or moments acting on the hull.

Exciting and restoring forces are dependent on the waves and on the shape of the hull in the vicinity of the waterline. S^3, SWATH, and MONOFORM hulls have considerably smaller waterplane areas than ordinary surface ships have. The small waterplane area is the main reason why these ships are much less responsive to wave motions than ordinary ships are.

The virtual mass (or virtual inertia in rolling and pitching) has two components: the actual mass of the ship and the mass of the water which is being accelerated by the ship. This "added mass" depends largely on the underwater shape of the hull.

Damping forces (or moments) have three main components: frictional, eddy-making, and wave-making. Damping can be conceived as dissipation of

energy from the kinetic-potential energy of the oscillating ship into the surrounding water. Reduced energy levels manifest in reduced amplitudes of the motion, thus the motion is said to be damped. Work is done by the ship in overcoming the frictional forces which always oppose the motion. Energy is also dissipated into the surrounding water because vortices are generated by the underwater hull. A ship oscillating at the free surface produces waves. Wave generation also dissipates energy, which is supplied by the oscillating ship. The magnitudes of the three damping components depend mainly on ship geometry. Frictional and eddy-making effects are governed by the form of the underwater hull, while wave-making depends mainly on the shape of the hull in the vicinity of the waterline.

Analytical evaluation of the factors governing the motion of the ship: exciting and restoring forces, added mass, and damping effects, is indeed a very tedious task which could not be performed during the time span of this study. A qualitative comparison of S^3 and MONOFORM geometries indicates the following possible differences in the factors governing seakeeping of each hull. For the same platform size and stability, MONOFORM has larger waterplane area than that of S^3. Larger waterplane area suggests an increase in exciting forces, restoring forces, and in the wave-making portion of damping. The V-shape of the struts would undoubtedly increase the added mass and the eddy-making portion of damping. It cannot be determined without further investigation whether these differences would improve or would degrade seakeeping characteristics of MONOFORM as compared to the S^3-SWATH designs. It is, therefore, proposed that the MONOFORM project be continued to investigate experimentally as well as theoretically the resistance and seakeeping characteristics of the MONOFORM hull, and to compare the findings with available data on S^3 and on SWATH.

SUMMARY AND RECOMMENDATIONS

The results of the 9-month investigation of the MONOFORM concept indicate that the single hulled MONOFORM ship is a viable alternative to the twin hulled S^3 and SWATH designs. MONOFORM has two major potential advantages over S^3 and SWATH: smaller wetted surface and lighter structure. Although smaller wetted surface indicates smaller resistance, the resistance characteristics of MONOFORM cannot be properly evaluated without model experiments conducted in a towing tank. Seakeeping characteristics of MONOFORM will be different from the seakeeping characteristics of S^3-SWATH ships, because of the radically different strut geometry. Seakeeping can be evaluated accurately only in a model towing tank while the ship model is exposed to waves.

It is recommended that the MONOFORM project be continued to answer the questions on resistance and seakeeping, and to perform a structural analysis of the MONOFORM design. Specifically, it is recommended to design and build an approximately 4.5-ft long model of the MONOFORM hull to be tested in VPI&SU's model towing tank. The main dimensions are to be selected from data generated in the parametric studies reported here. The model is to have the same displacement as NUC's model RC-1. Other dimensions to be chosen to provide at least the same military capability as expected from the RC-1 (deck dimensions, stability, etc.). Resistance tests on the model in calm water would establish horsepower requirements of a full scale prototype. Also, the stability (both transverse and longitudinal) of the model would be determined experimentally and compared with theoretical predictions. Model tests in waves would determine seakeeping characteristics which could be compared with the predictions of a to be developed analytical model. NUC's RC-1 model

or a copy of it should also be tested at VPI&SU's towing tank to establish a data base with which the MONOFORM results can be compared. Finally, a structural analysis of a full-scale prototype should also be performed and compared with the structure of the SSP. It is expected that the MONOFORM will have less structural weight per unit deck area than SSP has.

The above suggested research project could be completed within one to three calendar years, depending on the level of funding.

VPI&SU's Ship Model Towing Tank

The towing tank at Virginia Polytechnic Institute and State University is located in the basement of Norris Hall on the campus in Blacksburg, Virginia. The towing basin is 100 ft long and 6 ft wide. The nominal water depth in the tank is 4 ft. The towing carriage is electrically propelled and can attain a maximum speed of 3.0 meters per second. It has an electronic speed control and instrumentation for speed and drag measurements in calm water. The carriage was designed and manufactured by Kempf & Remmers of Hamburg, Germany. A simple wave maker is to be added for the seakeeping tests.

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APPENDIX A

1st PROGRESS REPORT

ON RESEARCH PROJECT ENTITLED:

"TO STUDY THE HYDROSTATIC AND HYDRODYNAMIC CHARACTERISTICS OF A NOVEL HULL FORM"

OFFICE OF NAVAL RESEARCH

CONTRACT NO. N00014-75-C-0599

MARCH 15, 1975

ADORJAN G. SZELESS

PRINCIPAL INVESTIGATOR

DEPARTMENT OF MECHANICAL ENGINEERING

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY

BLACKSBURG, VIRGINIA 24061

PARAMETRIC STUDIES

In an attempt to optimize the hull configuration a parametric study was initiated using digital computer techniques. Since one of the tasks of this research project is the comparison of the Monoform hull with the Naval Undersea Center's (NUC) Semi-Submerged Ship (S^3), the main characteristics used in the parametric study were selected to "resemble" those of model A of S^3, reference 2.

Figure 1, taken from reference 2, shows the geometry and dimensions of model A. Basic characteristics are: displacement of 49.1 lbs, corresponding to a submerged volume of 1360 cu. inches, 4 inch cylinder diameters, draft of 8 in. (=2D), and a free board of 4 in. The center of gravity is located at 7.23 inches, and the metacenter at 8.30 inches above cylinder centerline, resulting in a metacentric height of 1.07 inches.

The main parameters of the Monoform hull are shown in Figure 2. For convenience, during the computation all dimensions were expressed in feet. The "resemblence" between S^3 and Monoform can be seen from the data presented in Table 1.

Table A-1. Comparison of Main Dimensions

	S^3	Monoform
displacement volume	1360 cu. in.	∿1360 cu. ft
free board	4 in.	4 ft
waterline beam	26.4 in.	varies with β
CG above center of cylinder	60% of depth = 7.23 in.	62.5% of depth = 8.75 ft
cylinder length	34 in.	34 ft
strut length	25 in.	25 ft
strut thickness (average)	1 in.	1 ft
cylinder diameter	4 in.	5 ft
nomial draft	8 in. (2D)	10 ft (2D)

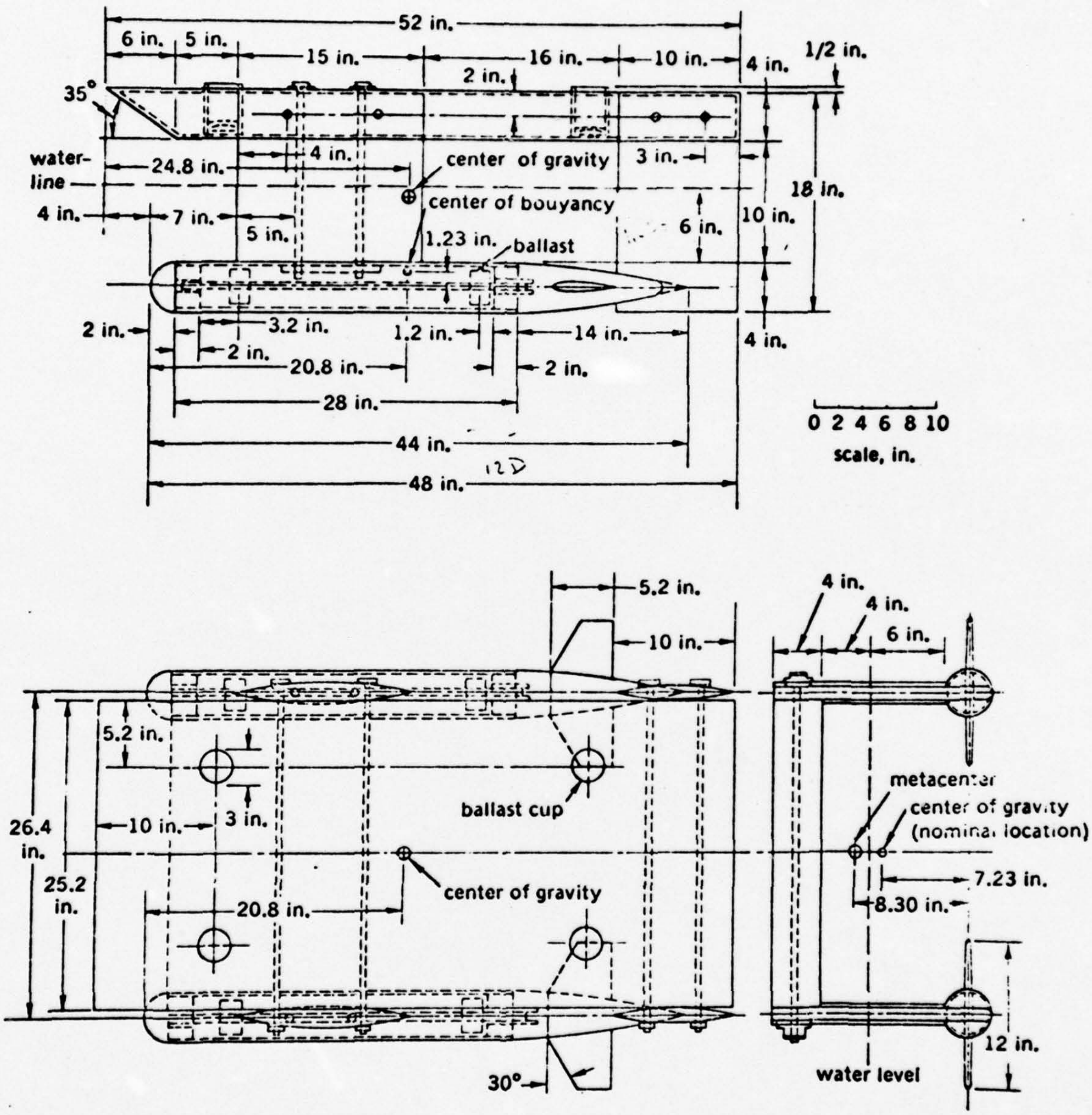
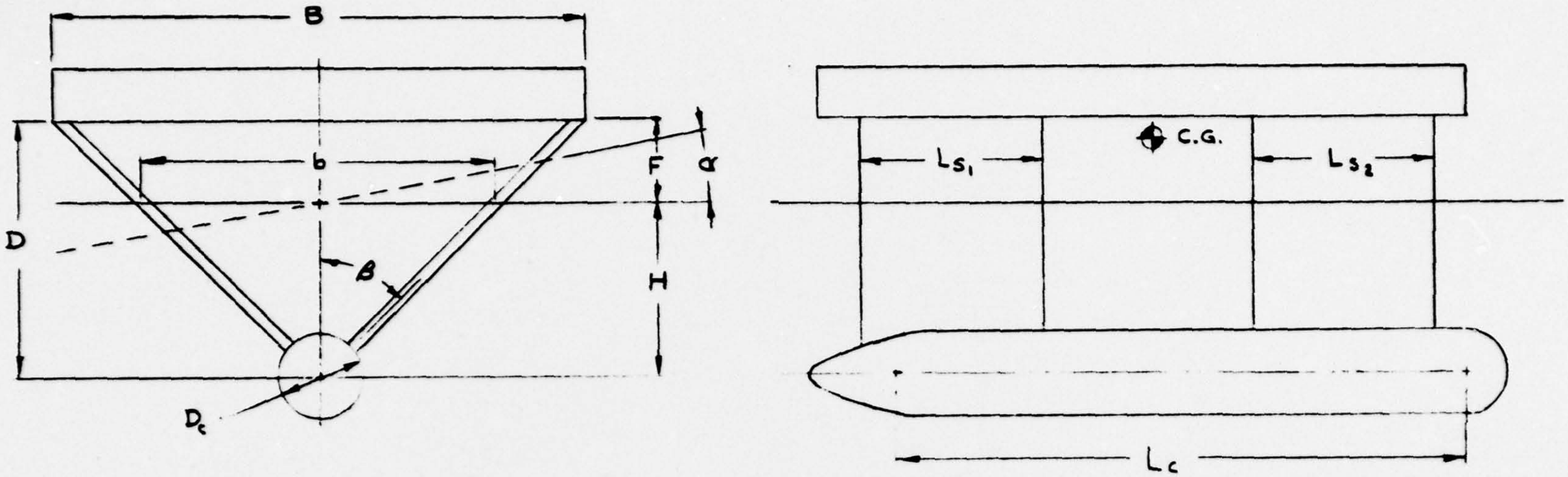


Figure A-1. S^3 - model A



$L_s = L_{s_1} + L_{s_2}$

α = ANGLE OF HEEL
β = ANGLE OF STRUT
D_c = CYLINDER DIAMETER
L_c = EQUIVALENT CYLINDER LENGTH
D = NOMINAL DEPTH

H = NOMINAL DRAFT
F = FREEBOARD
B = BEAM AT DECK
b = BEAM AT WATERLINE
L_s = COMBINED LENGTH OF STRUTS

Figure A-2. Monoform Parameters

Initial Stability

For stability evaluation, the draft H, strut angle β, and heel angle α, were systematically incremented while cylinder and strut dimensions were held constant. In addition to stability parameters for each combination of H, α and β, displacement volume and wetted surface were also computed. At a nominal draft of 10 feet for a 5 foot diameter cylinder, it was found that a strut angle of 52 degrees is necessary to obtain the required displacement. For this configuration, which was selected for stability comparison only, the displacement is 1355 cu. ft; the waterline beam is 25.60 ft; and the beam at deck is 37.46 ft. In this configuration, S^3 and Monoform differ only in cross-section; they have the same dimensions and appearance viewed in profile; therefore, only the cross-sections are shown for comparison in Figure 3. The basic dimensional difference between the two hulls is the wider beam of the Monoform. The wide beam might be either an advantage or a disadvantage, depending on the application. The slightly deeper draft of Monoform might not be considered disadvantageous.

The center of gravity is shown to be lower for the Monoform than for S^3. Structural weight calculations were not performed, rather the center of gravity locations were taken proportional to the depths of the hulls and struts (60% for S^3, and 62.5% for Monoform). This assumption seems to be reasonable.

The initial portion of the righting moment versus heel angle curves for both hulls are presented in Figure 4. The Monoform is markedly more stable than S^3. It would take about twice as much heeling moment to produce the same inclination for the Monoform than for S^3. Conversely, the same heeling moment would cause half as much angular displacement of the Monoform

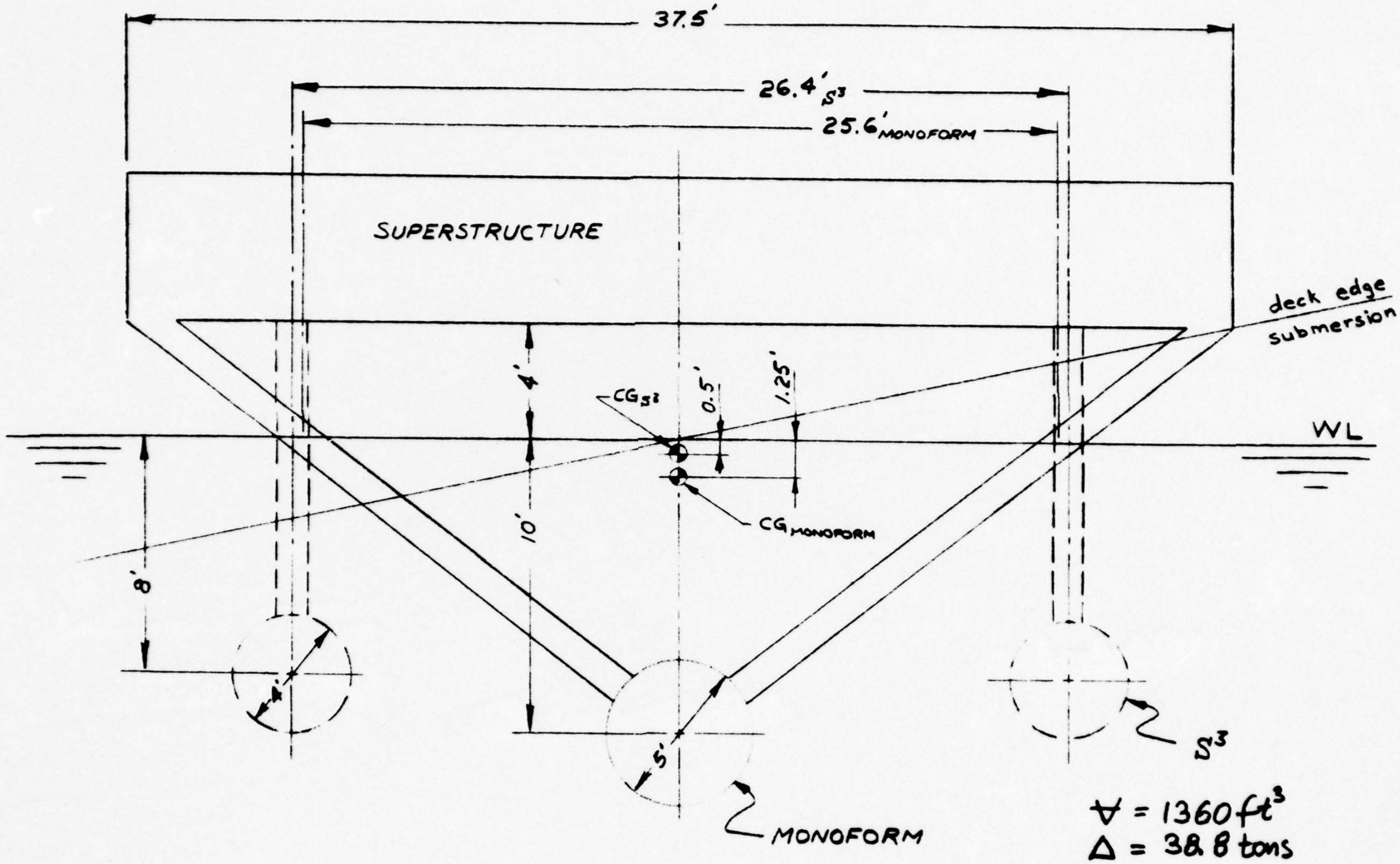


Figure A-3. MONOFORM and S^3 Comparison.

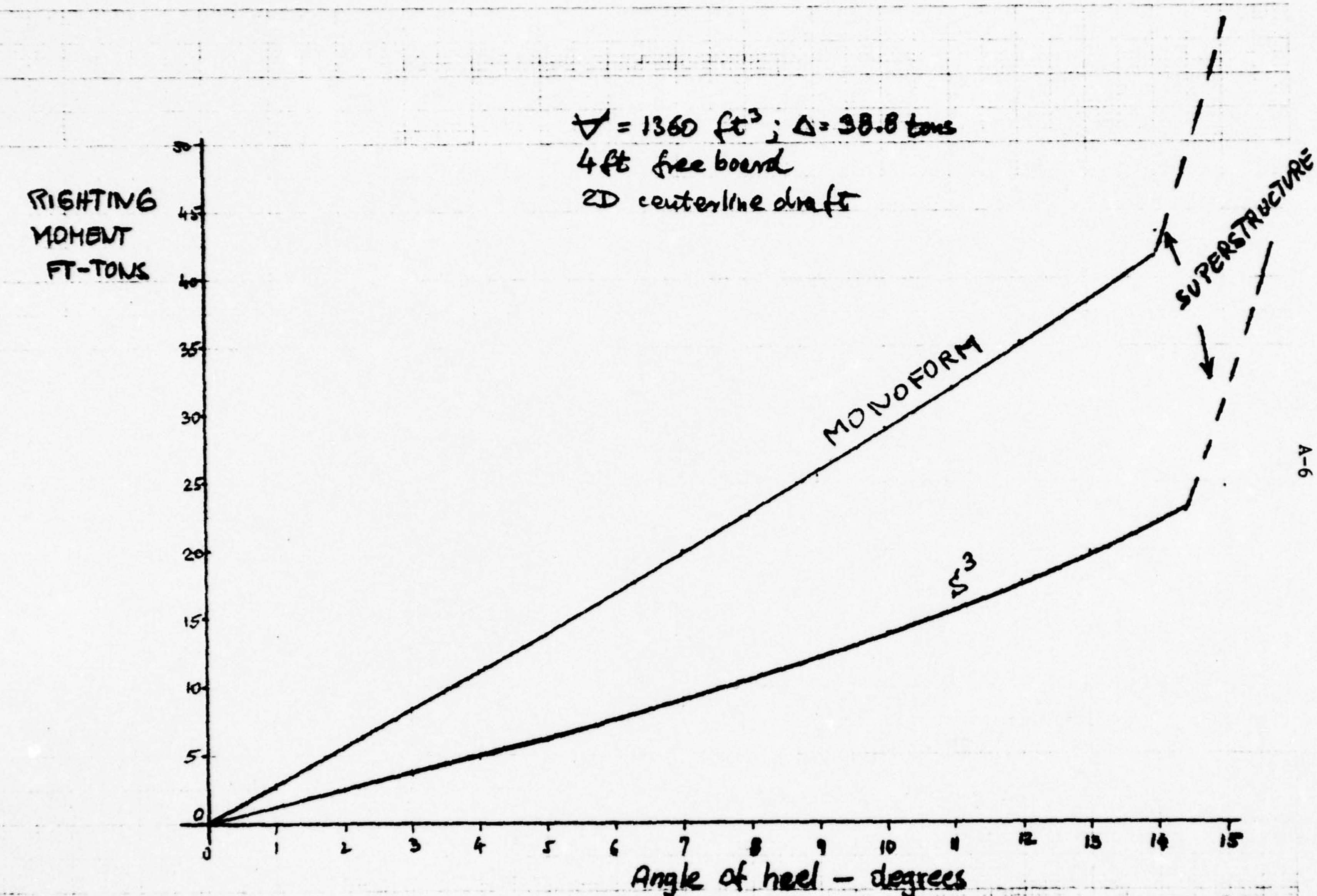


Figure A-4. MONOFORM S^3 Stability Comparison

hull than of S^3. The reason for better stability is the larger change in displacement of the struts during heel for the Monoform than for S^3. The initial slope of the righting moment curve, which is proportional to the metacentric height, is steeper for Monoform than for S^3. The reason for the larger metacentric height is the larger water plane area of the Monoform. At the same strut thickness, the water plane area is larger for the V-struts than for the vertical ones, because the waterline cuts the struts at oblique angles and not at right angles as is the case for the vertical struts of S^3.

One disadvantage of the Monoform geometry chosen for stability comparison is its slightly larger wetted surface than that of S^3. Wetted surface and displacement volume data are presented in Table 2 for comparison.

Table A-2. Volumes and Wetted Surfaces

		S^3	Monoform
Volume:	cylinder	925 ft^3 = 68%	668 ft^3 = 49%
	struts	435 ft^3 = 32%	687 ft^3 = 51%
	total	1360 ft^3 = 100%	1355 ft^3 = 100%
Surface:	cylinder	930 ft^2 = 51%	613 ft^2 = 31%
	struts	887 ft^2 = 49%	1374 ft^2 = 69%
	total	1817 ft^2 = 100%	1987 ft^2 = 100%

As it is shown in the table the contribution of the struts both to displacement and to wetted surface is much larger for the Monoform model than for the S^3. The increase in wetted surface is disadvantageous, because it tends to increase resistance as well.

Monoform Design Charts

The unexpectedly large wetted surface of the Monoform model chosen for stability comparison indicated a need for a systematic study of all significant

hull parameters with the object of developing a means of selecting "optimal" hull dimensions. Once again, a computerized approach was taken to develop "design charts" which, in reality, are graphical representations of the interdependence of the hull parameters. The development of the charts are in progress at this writing. These charts show variations in geometry of a monoform ship as a function of cylinder diameter. The main characteristics resemble those of the 190 ton SSP Kalimalino whose main dimensions are shown in Figure 5, taken from reference 3. Table 3 summarizes the pertinent data.

Table A-3. Basic Characteristics of a 190-ton Monoform Hull

Displacement	190 tons
Displacement Volume	6650 ft^3
Free Board	6 ft
Cylinder Submergence	1.85 D
Strut Total Length	0.7 x cylinder length
Strut Thickness Ratio	0.07

From the early stage of the design study four charts are presented as examples in Figures 6 through 9.

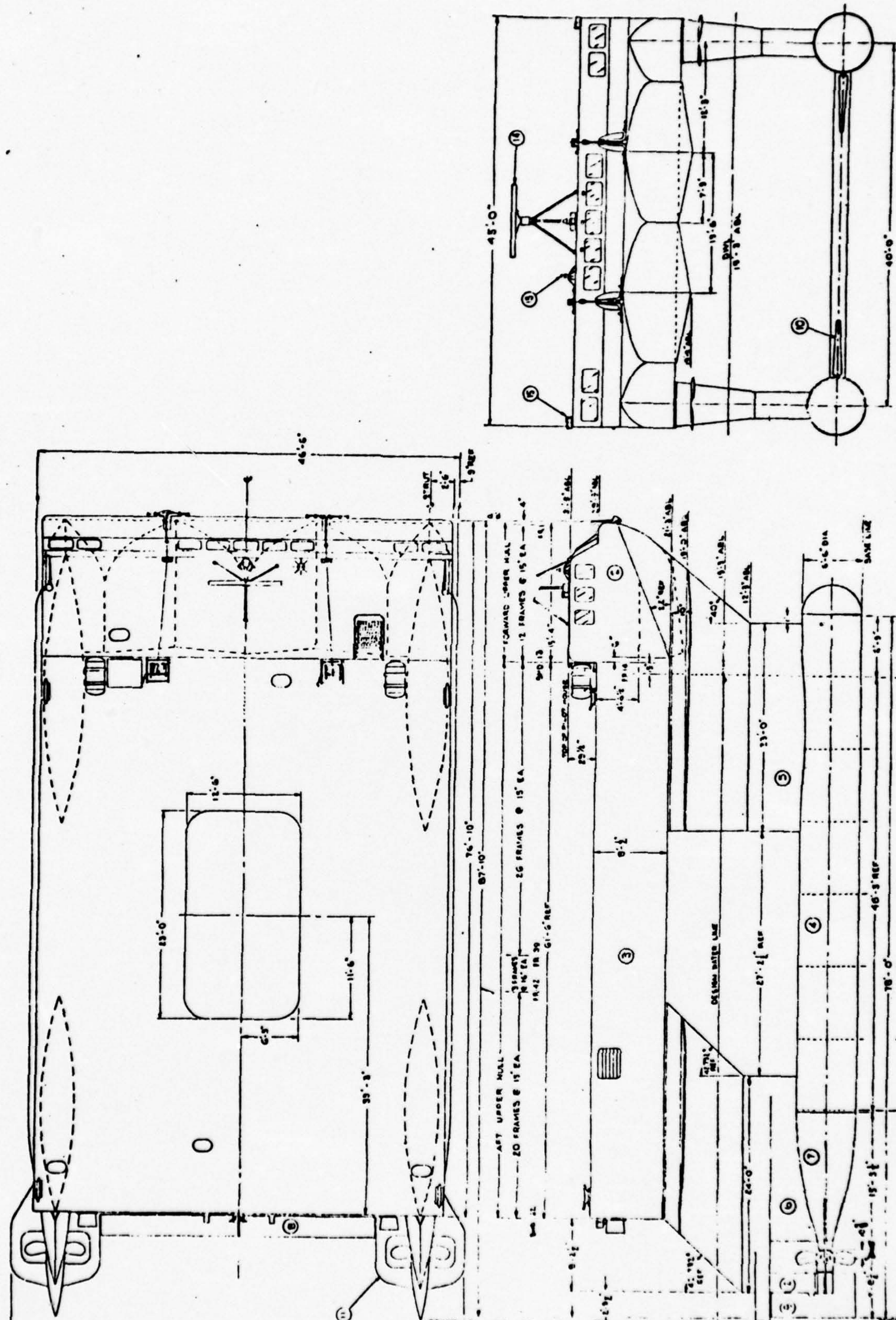


Figure A-5. SSP Dimensions

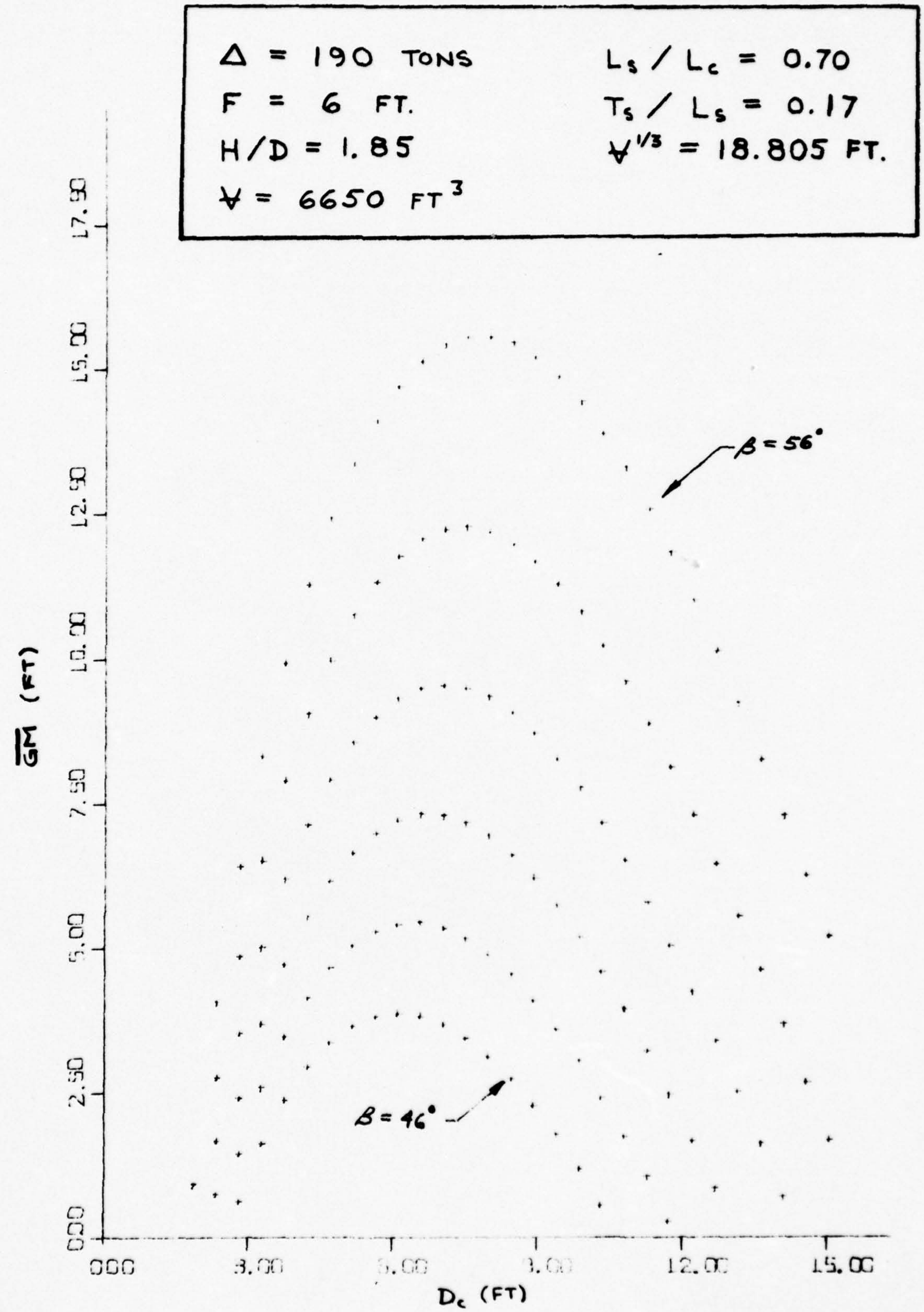


Figure A-6. Variations in Metacentric Height

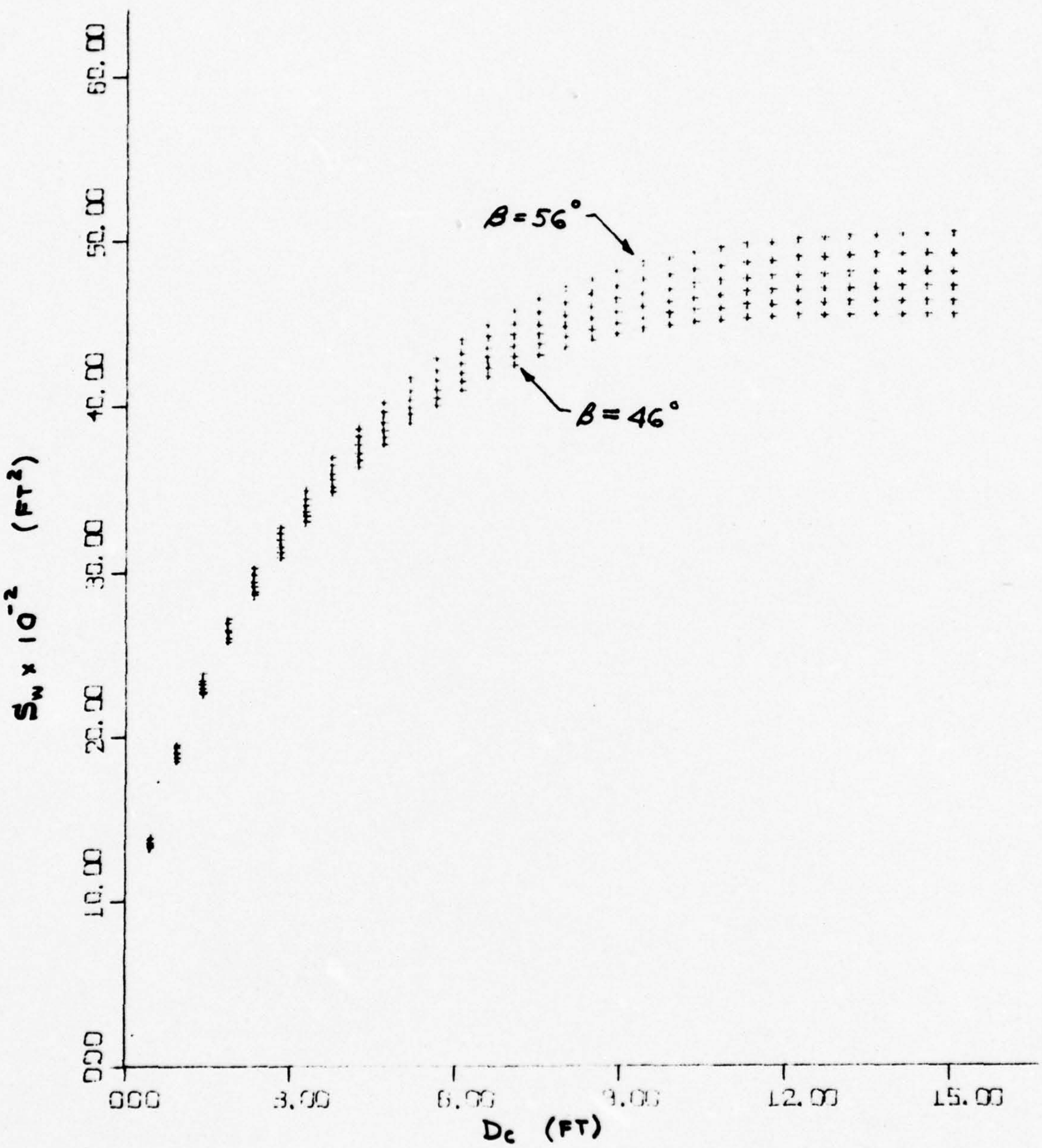


Figure A-7. Wetted Surface

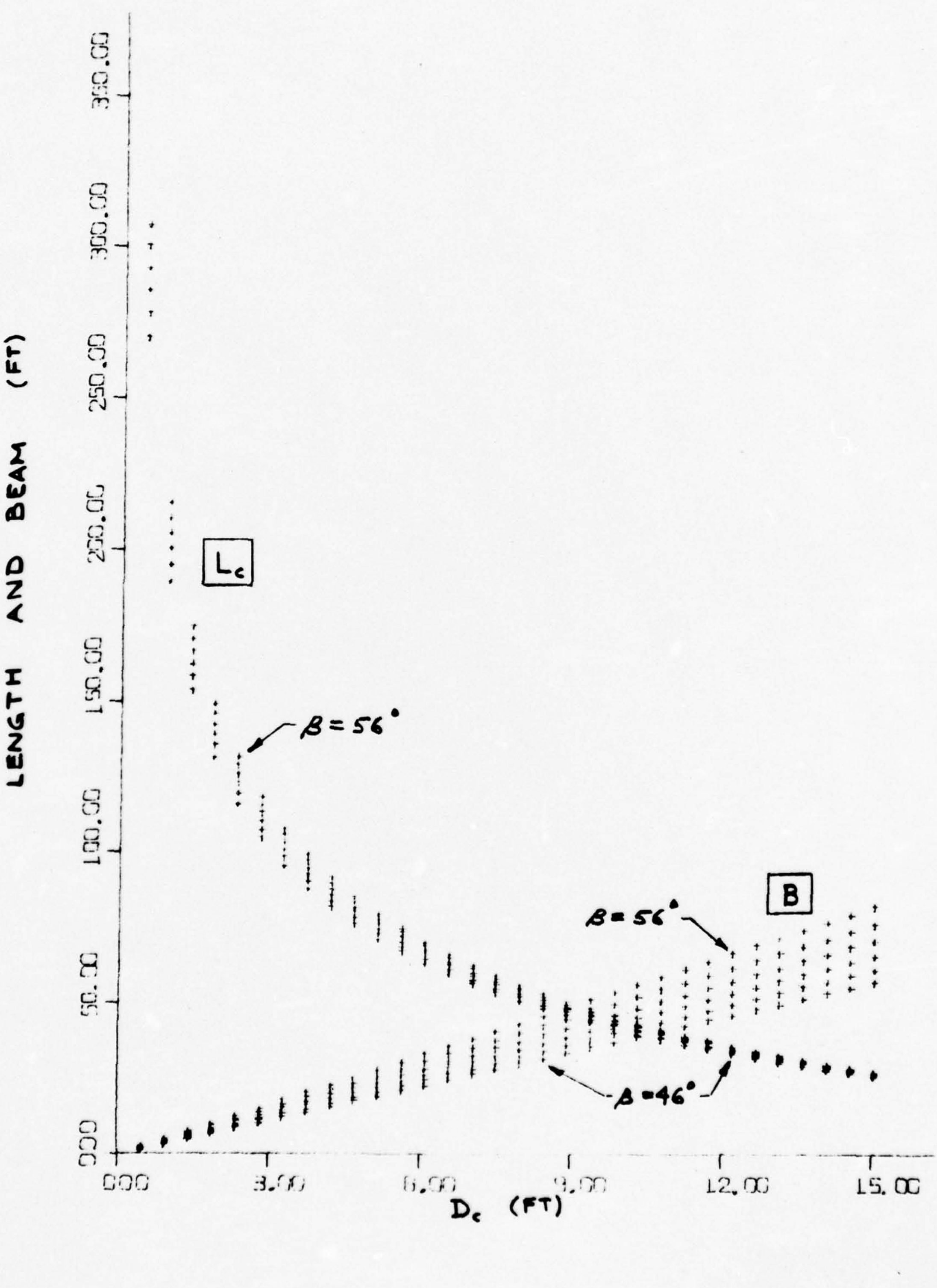


Figure A-8. Length and Waterline Beam

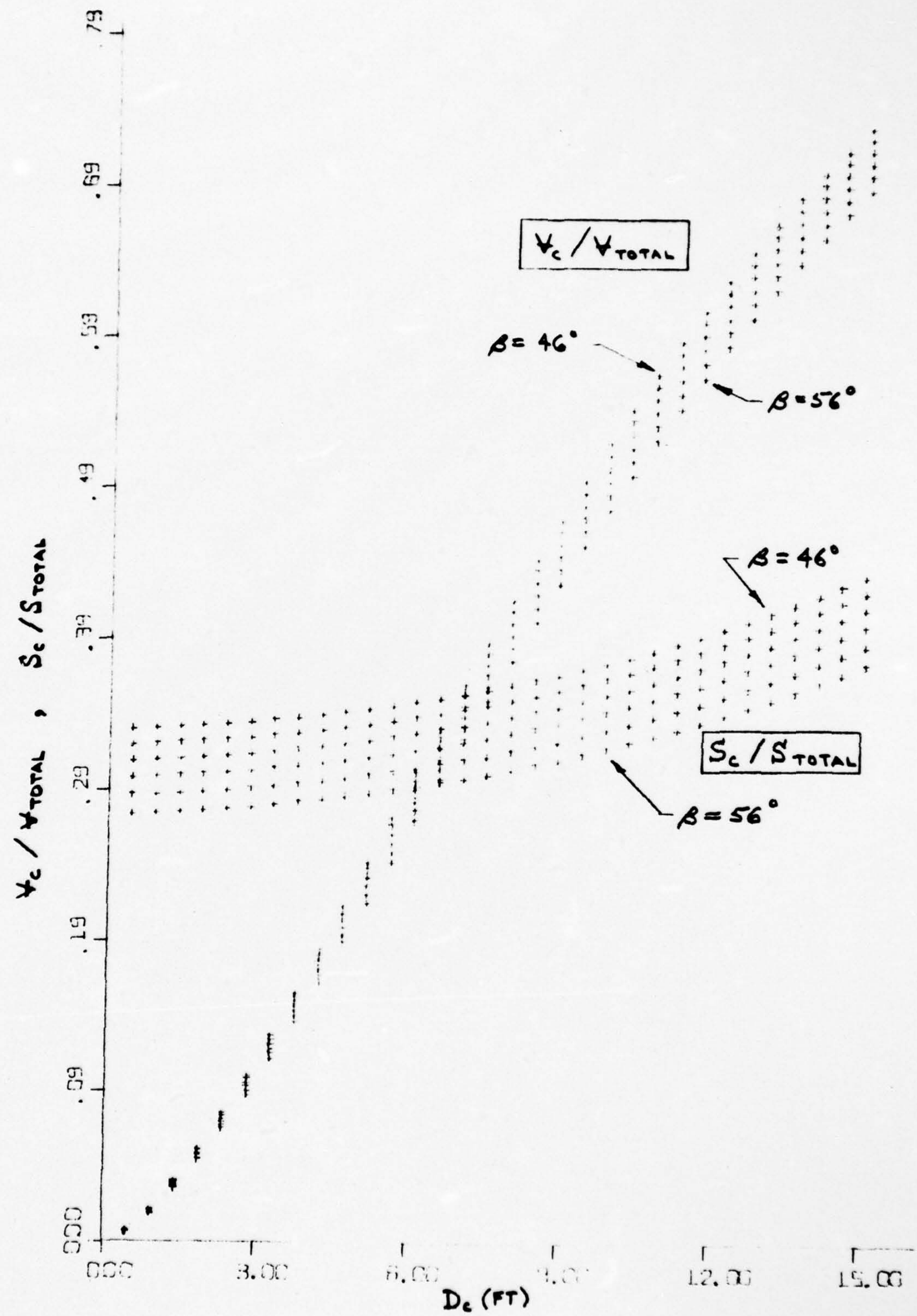


Figure A-9. Cylinder Volume- and Surface-Fraction

The design charts can be used as follows. For a desired metacentric height, Figure 6 represents possible combinations of cylinder diameter and strut angle. Figure 7 shows the wetted surface as a function of diameter and strut angle. For the strut angles considered (46°-56°), the wetted surface peaks between 12 and 15 feet cylinder diameter. Since it is desired to keep wetted surface at a minimum, cylinder diameters either above or below this range would be more advantageous. Figure 8 shows, for a given diameter and strut angle, the length of the cylinder and the beam at the waterline. These values are indicative of the overall dimensions of the hull. Finally, Figure 9 shows the contribution of the cylindrical hull to the total volume and wetted surface of the underwater hull.

It must be emphasized that this design parameter study is by far not complete. One obvious drawback is the fixed strut to cylinder length ratio, which results in wetted surface penalty for long cylinders. This will be removed by imposing a longitudinal stability requirement in place of the fixed lengths ratio.

Outline of Further Work

The design charts described above are based on systematic changes in the hull cross section geometry. It appears at present, that significant reduction in wetted surface can be achieved by changing the longitudinal configurations of the struts. This investigation will be undertaken on digital computer as the next phase of the project.

To be able to meaningfully compare "optimal" Monoform characteristics with S^3 and, more preferably, with the 190-ton SSP Kalimalino, more technical data are needed on these hulls. Contact with NUC will be established to obtain these data.

The hydrodynamic investigations will be undertaken after a reasonably satisfactory geometry for the Monoform had been selected.

APPENDIX B

2nd PROGRESS REPORT

ON RESEARCH PROJECT ENTITLED:

"TO STUDY THE HYDROSTATIC AND HYDRODYNAMIC CHARACTERISTICS OF A NOVEL HULL FORM"

OFFICE OF NAVAL RESEARCH

CONTRACT NO. N0014-75-C-0599

July 1, 1975

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Table of Contents

INTRODUCTION

Two sets of parametric studies were conducted during the second three-month period of the MONOFORM project. Both studies were based on the same size (190 ton) hull but with differring strut geometries.

The first set of computations were performed on a hull form with type A struts. The type A struts are cylindrical with constant lenticular cross sections, not unlike those of NUC's 190-ton SSP. The second set of computations were based on tapered (Type B) struts. These have lenticular cross sections at the waterline which gradually change into streamlined cross sections at the point of intersection with the underwater cylindrical hull.

The results of the parametric studies are presented graphically in so called design charts. The basic hull configuration, the parameters varied, as well as those held constant in the analyses are described in detail for both sets of computations.

A further set of parametric studies based on lift producing struts is still in progress at the time of this writing, thus results cannot be included in this report.

STRUT TYPE-A

Description of Model A

The general arrangement of the hull and the main parameters used with strut A are shown in figure 1. The MONOFORM hull is composed of a mostly cylindrical underwater hull of length L_{max}, and 4 struts arranged in V-format, each of length L_s. Although the parametric study was conducted with the help of a digital computer and, therefore, all computations had to be performed numerically, the program can be exercised for any size hull by changing only a few basic initial data. For the presentation which follows, the basic dimensions were selected such as to permit relatively easy comparisons with NUC's SSP design, which is used throughout as an existing and well documented peer hull.

As is shown in figure 1, the underwater hull is composed of a circular cylindrical section of diameter D, and of length $(L_c - D)$. The nose of the hull is a hemisphere of diameter D, and the tail section is a circular cone of length 2D. Thus, the total length of the underwater hull is: $L_{max} = L_c + 1.5D$.

Each of the 4 struts (of type A) have the same length L_s and identical lenticular cross-sections composed of two circular arcs. The thickness to length ratio of each strut is fixed at $\frac{T_s}{L_s} = 0.17$. The struts are cylindrical, i.e., leading and trailing edges are parallel. In other words, the strut cross-sections are not changing with elevation. (This is discussed here in some detail because this is the area where the difference between struts A and B lies). In the profile view of figure 1, the struts' leading and trailing edges are perpendicular to the cylinder's centerline. The leading edge of the front strut is at the front end of the cylindrical hull. The trailing edge of the aft strut meets the underwater hull at the midpoint of the conical tail section. The locations of the strut edges just described relative to the cylinder remained

NOMENCLATURE:

B = overall beam at deck

B_{WL} = beam at waterline (nominal)

D = cylinder diameter

F = freeboard

H = draft to cylinder center line

G = center of gravity

L_c = cylinder length (nominal)

L_{max} = overall length of hull

L_s = strut length

T_s = strut thickness

β = strut angle

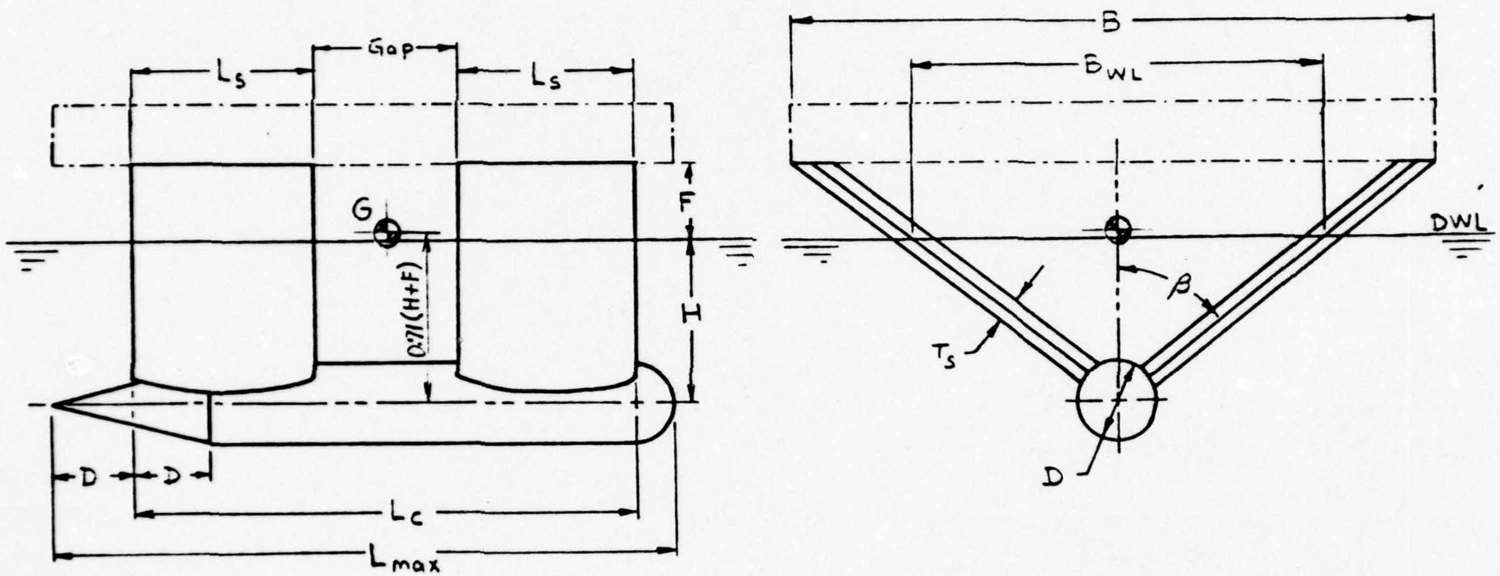

Figure B-1. Geometry and Nomenclature for Parametric Analysis: Strut Type A

fixed as the strut length was varied during the systematic parametric analysis. In other words, the trailing edge of the front strut and the leading edge of the aft strut were relocated whenever the lengths of the struts were changed. The cross sectional view shows the strut angle β, which was kept fixed at 52°. The freeboard F, the distance between waterline and the lower deck edge of the super-structure was also held constant at a value of 6 feet (same as for SSP). The displacement of the ship was assigned the constant value of 190 tons. The center of gravity of the fully loaded ship (Δ = 190 tons) was assumed to be above the cylinder center line at 71% of the vertical distance between cylinder centerline and deck edge (71% of H + F).

The geometrical features described (with the exception of the strut angle β) were selected such as to maintain the closest resemblance (symmetry is not possible) to the SSP. Figure 1a taken from reference 4, shows the main features of the SSP. It is included here for convenience of comparison. The selection of the strut angle was somewhat arbitrary. The 52° value was used only because this appeared in the previous progress report. By no means should it be considered as an optimum value, although it is probably close to the optimum.

The following dimensions were changed systematically during the parametric study: diameter (D), draft ratio (H/D), and the percent gap between struts ($PG = \frac{Gap}{L_s} \times 100$). The range of values covered are given in table 1 below.

Table B-1

Range of Parameters

D : 5-7 feet in increments of 0.1 ft

H/D: 2.0-1.0 with intermediate values of 1.85, 1.60, 1.40, 1.20

PG : 0-250% in steps of 50%

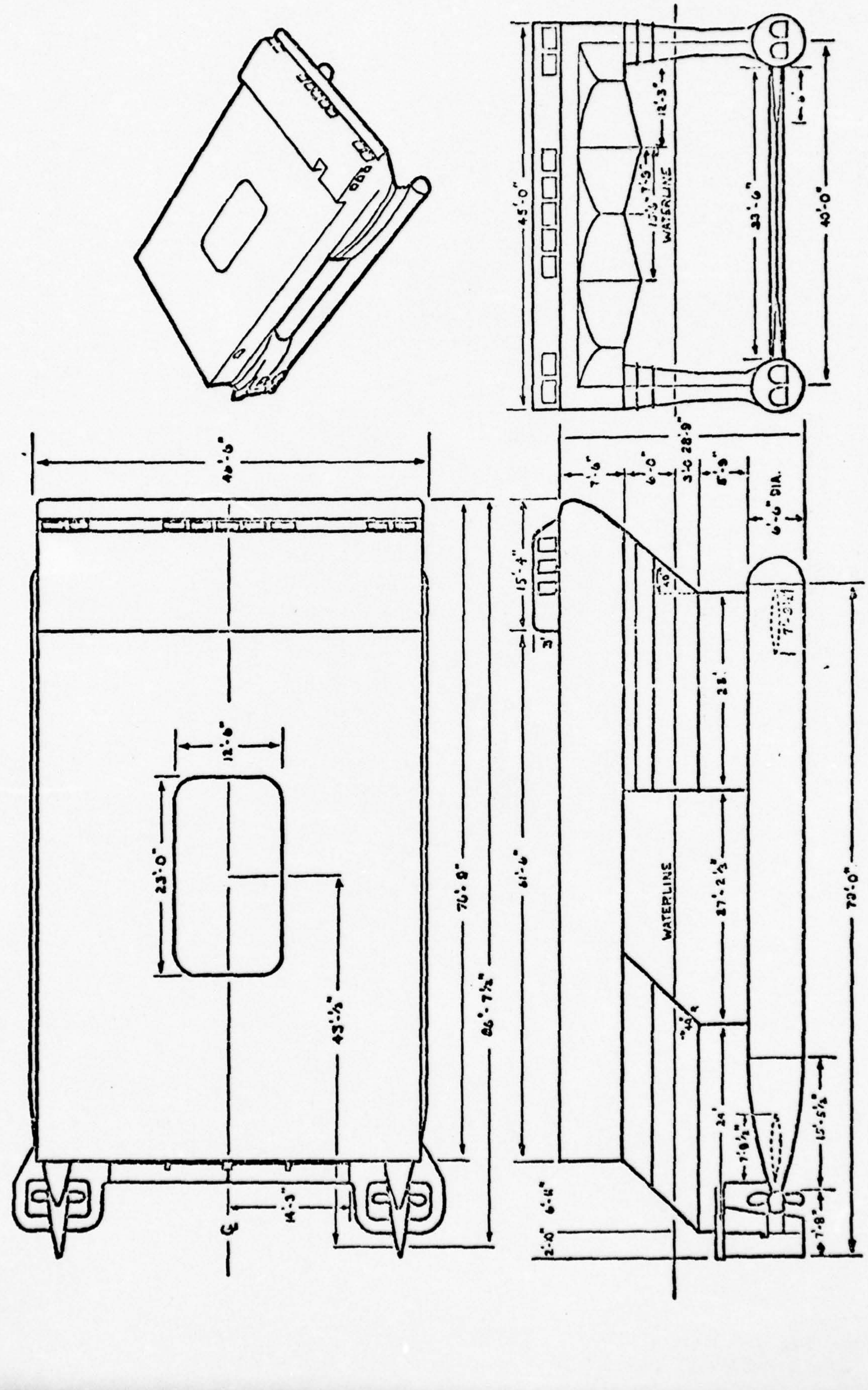

Figure B-1a. Dimensions of the SSP

For sake of brevity, only the graphical representations of the results are included in this progress report, and only those for H/D = 2.0, 1.85, 1.60, and 1.40, because the draft ratios of 1.0 and 1.20 seem unrealistic for practical applications.

Design Charts of Model A

The results of the first set of parametric analyses conducted on MONOFORM hull with type A strut configuration are presented graphically in figures 2 through 24. To improve readability of the report these figures were placed at the end of this section. The analysis was performed on the digital computer with a constant displacement of 190 tons and with a constant strut angle of 52 degrees as follows.

Step 1: The value of the centerline draft to cylinder diameter ratio (H/D) was set (at first to 2.00) and was held constant during the execution of the rest of the program.

Step 2: The cylinder diameter was assigned a value (at first 5.0 ft) and was held constant.

Step 3: The percent gap, which is defined as the gap between struts (see figure 1) divided by the length of a strut was assigned a value, at first 0%. (Note that this case is rather unrealistic since the leading edge of the aft strut coincides with the trailing edge of the fore strut).

Step 4: With the above values of: displacement, strut angle, draft, diameter, and strut spacing, the length of the cylinder and the length of the struts were computed to obtain the required displacement. The geometry thus fixed (strut thickness to chord length ratio was also held constant throughout at 0.17), the

location of the center of buoyancy was computed as well as longitudinal and transverse moments of inertia of the waterplane. These yielded the transverse and longitudinal locations of the metacenters. The metacentric heights were then computed assuming that the vertical location of the center of gravity was in each case at 71% of the distance between cylinder centerline and the lower surface of the superstructure. Finally, from the known geometry, the wetted surface was also computed.

Step 5: The computation from here returned to Step 4 after the percent gap was incremented by 50%. The incrementation of the percent gap was repeated until the maximum value considered realistic, 250%, was reached. Next, the cylinder diameter was incremented by 0.1 ft and the computations were repeated from Step 3 until the maximum selected value of the diameter, 7.4 ft was reached. Finally, the draft ratio was decreased in steps to 1.85 (the draft ratio of SSP), 1.60, 1.40, 1.20 and 1.00. The computations starting at Step 2 were now repeated. The last two sets of the draft ratio (H/D = 1.20, 1.00) are considered unrealistic, and are not presented in this report.

The so called design charts (figures 2 through 24) are plotted as functions of the cylinder diameter (5.0 through 7.4 feet). Where appropriate, lines of constant percent gap between struts (0, 50, 100, 150, 200, and 250%) are drawn on the charts. The two heavy lines labeled 1 and 2 represent constant values of metacentric heights, $\overline{GM}$ = 4.5 ft and $\overline{GM}_L$ = 15.7 ft, respectively. These are the metacentric heights of the SSP. All points within the triangular areas represent a MONOFORM hull with larger metacentric heights in both directions than those of the SSP.

For each value of H/D considered, five design charts were prepared. The first chart of each group shows the cylinder length (as defined in figure 1), the second one the strut length, the third one the transverse metacentric height, the fourth chart shows the longitudinal metacentric height, and finally the fifth one shows the wetted surface. The last three charts (figures 22-24) show the draft, waterline beam, and maximum beam at deck level as functions of diameter and H/D. (Figures 22 and 23 apply also to strut B configuration).

The following example indicates the use of the design charts in the selection of the main dimensions of a MONOFORM hull of 190 tons displacement, 52 degrees strut angle, 17% strut thickness to chord length ratio, same size struts fore and aft, 6 ft freeboard, and of 71% elevation of the center of gravity. In addition to the above constants, an H/D of 1.85 (SSP) is selected. A percent gap of 100%, being close to that of SSP is also arbitrarily chosen. (The optimum gap size between struts is to be defined by hydrodynamic analysis and by model tests). For cylinder diameters of 5.0, 6.0, and 7.0 feet the values obtained from figures 7 through 11, and 22 through 24 are shown in Table 2. For comparison, data available on SSP are also tabulated.

Table B-2.

MONOFORM Characteristics for 100% Strut Gap, H/D = 1.85, Strut A

	D = 5.0 ft	D = 6.0 ft	D = 7.0 ft	SSP (D = 6.5 ft)***
$L_{cylinder}$	87 ft	75 ft	64 ft	55 ft
L^{*}_{max} (hull)	94.5 ft	84 ft	74.5 ft	74 ft**
L_{strut}	29 ft	25 ft	21.3 ft	24 ft
B_{WL}	23.7 ft	28.4 ft	33.2 ft	40.0 ft
B (at deck)	47.1 ft	50.7 ft	54.3 ft	45.0 ft
Draft to Keel	11.8 ft	14.1 ft	16.4 ft	15.2 ft

Table B-2. continued . . .

	D = 5.0 ft	D = 6.0 ft	D = 7.0 ft	SSP (D = 6.5 ft)***
$\overline{GM}$	6.3 ft	5.9 ft	4.7 ft	4.5 ft
$\overline{GM}_L$	75 ft	37 ft	15 ft	15.7 ft
S_W	3970 ft^2	4230 ft^2	4340 ft^2	4830 ft^2

*$L_{max} = L_{cyl} + 1.5D$

**Total length of cylinder; deck is 77 ft long.

***SSP data from reference 4

If, for example, the 6 ft diameter version of MONOFORM was selected from Table 2, one would have a platform with a deck area of at least 84 ft by 51 ft, while the SSP has a total deck area (including deck house) of only 77 ft by 45 ft. In addition, the metacentric heights of the MONOFORM would also be larger than those of the SSP, indicating a more stable platform. In the transverse direction the MONOFORM'S 5.9 ft metacentric height is 1.31 times larger than SSP's 4.50 ft, and in the longitudinal direction the 37 ft metacentric height is 2.36 times larger than the 15.7 ft metacentric height of the SSP. The 4230 sq ft wetted surface of MONOFORM is 87.5% of the 4830 ft^2 of the SSP. Assuming (as a first approximation) that the drag coefficients are the same for both hull forms, the smaller surface indicates a 12.5% reduction in power requirement in favor of MONOFORM.

It must be emphatically pointed out though that the above comparisons might not be completely fair in all respects because of the inherent differences in the geometries of the two hulls. For one thing, the fore and aft struts of the SSP are not of the same length (although the difference between them is not very large), neither are they completely vertical and parallel in

profile as are the A-type struts of MONOFORM.

The assumption of an equal displacement of 190 tons and of similar military capabilities implies that the MONOFORM must have the same payload capacity as the SSP has. Disregarding the possibility of reduced power requirement for the MONOFORM (drag coefficients were not evaluated yet) with associated reduction in weights of power plant and fuel, MONOFORM must not have larger structural weight than SSP has. Structural computations for the MONOFORM have not been performed, therefore, the weight of the structure cannot be ascertained at the present time. However, the following argument is offered to show that the structural weight of the two ship types are approximately equal.

The MONOFORM has only one underwater cylinder while SSP has two. On the other hand, the struts of the MONOFORM are longer due to their inclined positions than the vertical struts of SSP. The weight reduction in the cylinder and the weight increase in the struts probably cancel each other. The total deck area of the MONOFORM (84 x 51 = 4284 sq ft) is larger by 819 sq ft than that of the SSP (77 x 45 = 3465 ft^2). The increased structural weight associated by the larger deck area is probably balanced by reduced strength requirements at the joints of the struts with the deck. As can be seen from the sectional views in figures 1 and 1a, the structure of the MONOFORM is of a closed triangular shape, while the structure of the SSP is of an open, inverted U-shape. As a result, the struts of the SSP must transmit large lateral moments to the deck structure (cantilever joint), while the struts of the MONOFORM transmit no lateral bending moments to the deck and, therefore, their connection might be of a simple pin-joint type.

It must be pointed out once again, that the above comparison between SSP and MONOFORM is based on an arbitrarily selected MONOFORM configuration, which by no means may be considered an optimum one. There is no assurance that the

52° strut angle is the most desirable one, that the 1.85 draft ratio is optimal, or that the 100% gap between the struts is better than a larger or a smaller gap. The comparison between the two hull forms is intended to demonstrate the merits of the MONOFORM hull, even if its dimensions are not optimized. The computer model used to generate the data shown graphically in figures 2 through 24 can be exercised for any hull size, strut angle, etc.

Even though the MONOFORM hull with type A struts appears to be superior in many respects to the SSP form, a new strut form, named type B, was devised to improve stability and to further reduce wetted surface of the MONOFORM hull.

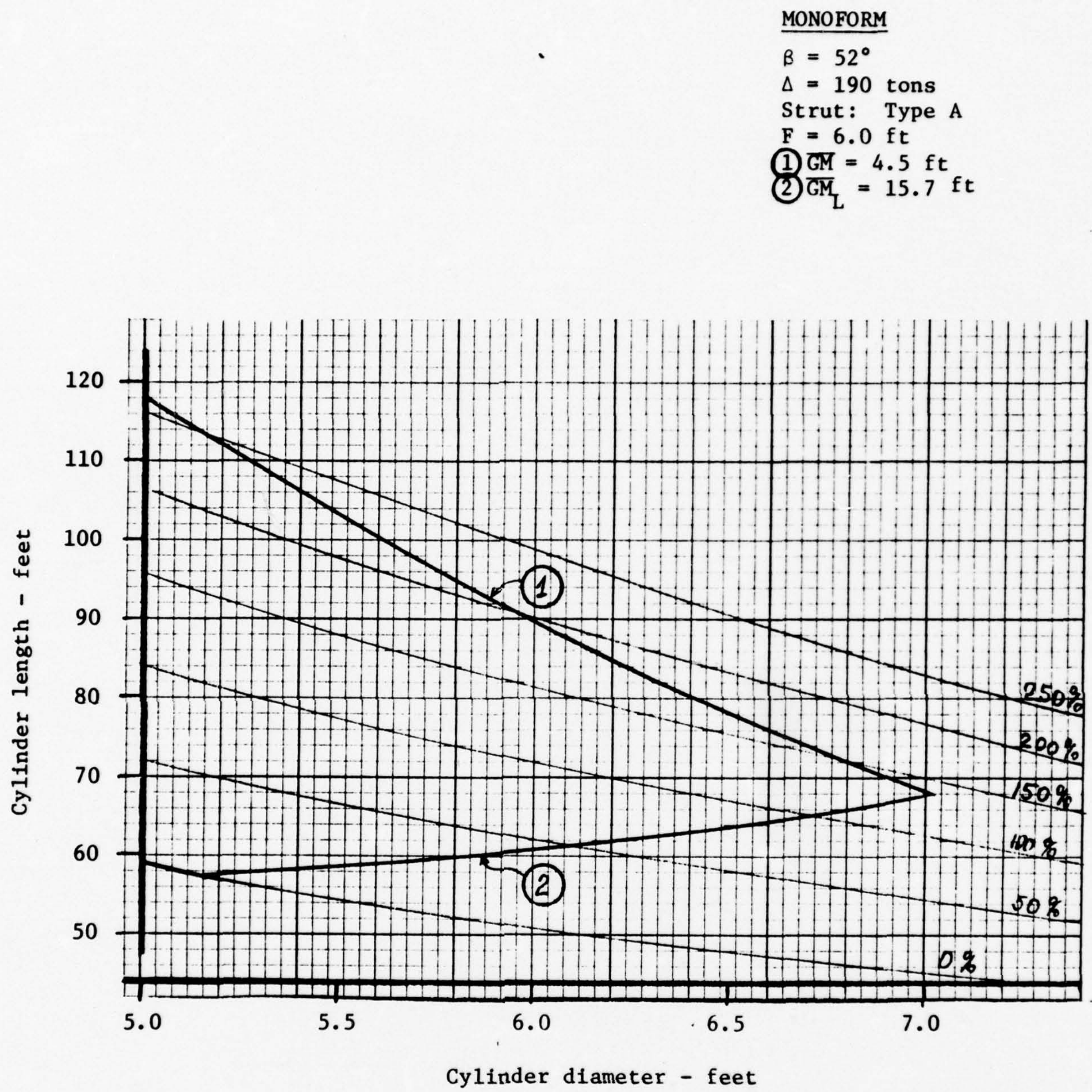

Figure B-2. Cylinder length chart for H/D = 2.0

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
1 $\overline{GM}$ = 4.50 ft
2 $\overline{GM}_L$ = 15.7 ft

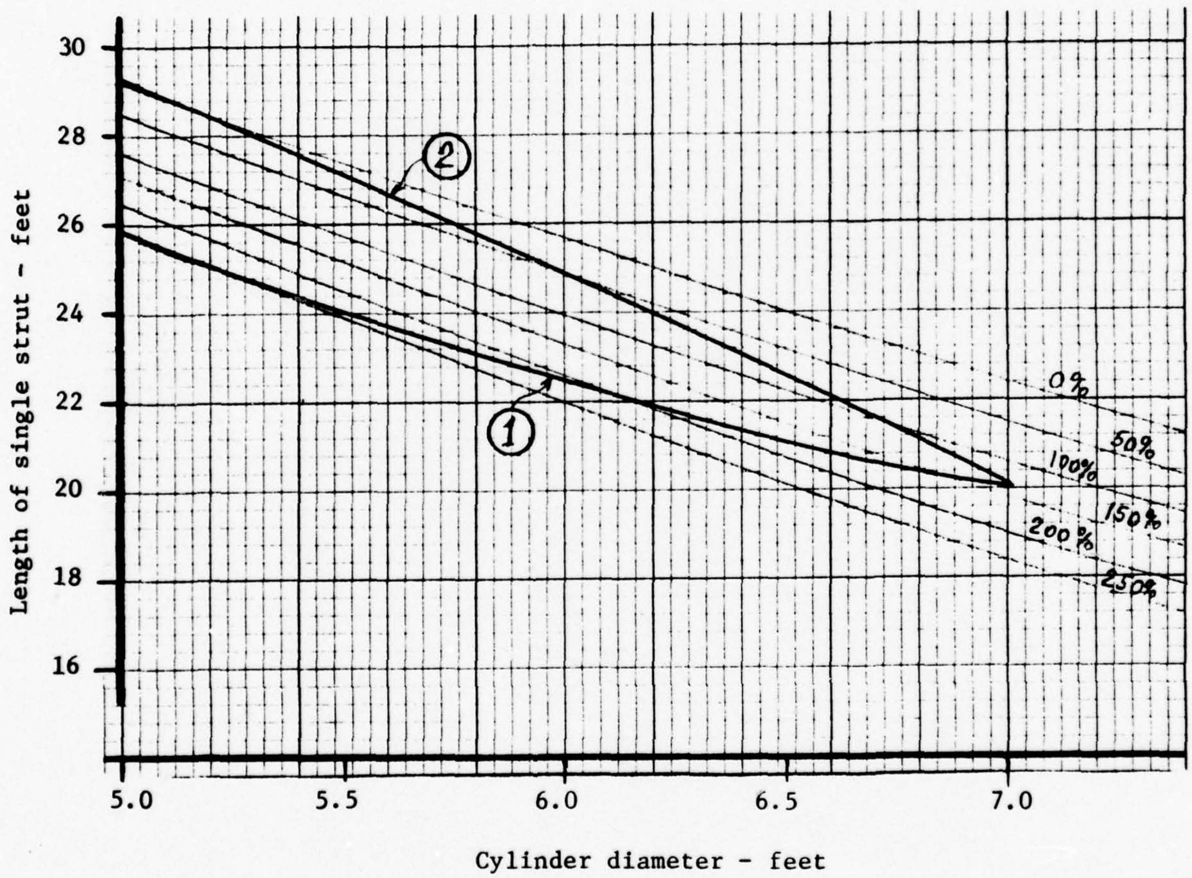

Figure B-3. Strut length chart for H/D = 2.0

MONOFORM

β = 52°
Δ = 190 tons
Strut: Type A
F = 6.0 ft
① $\overline{GM}$ = 4.5 ft
② $\overline{GM}_L$ = 15.7 ft

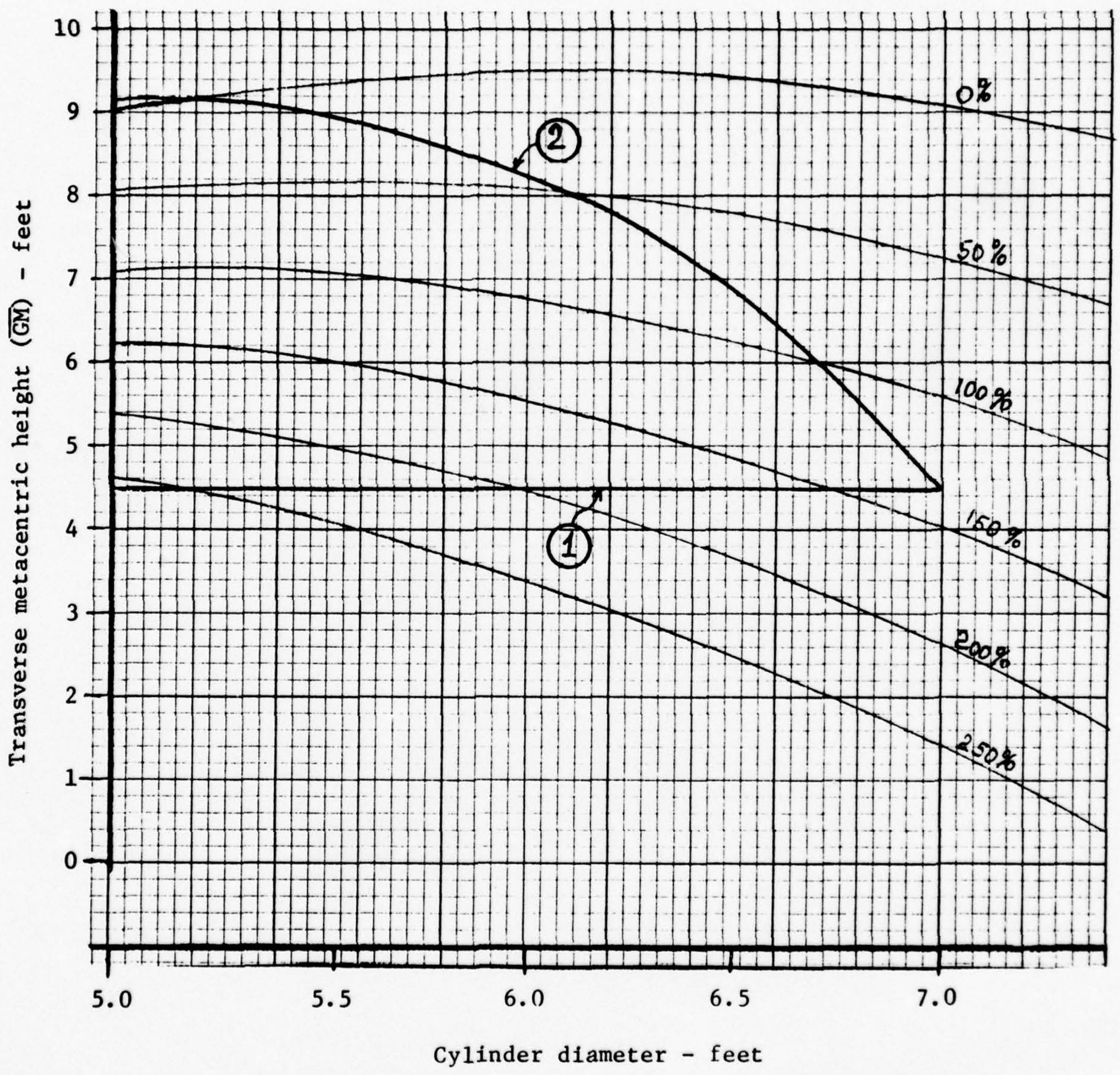

Figure B-4. Transverse metacenter chart for H/D = 2.0

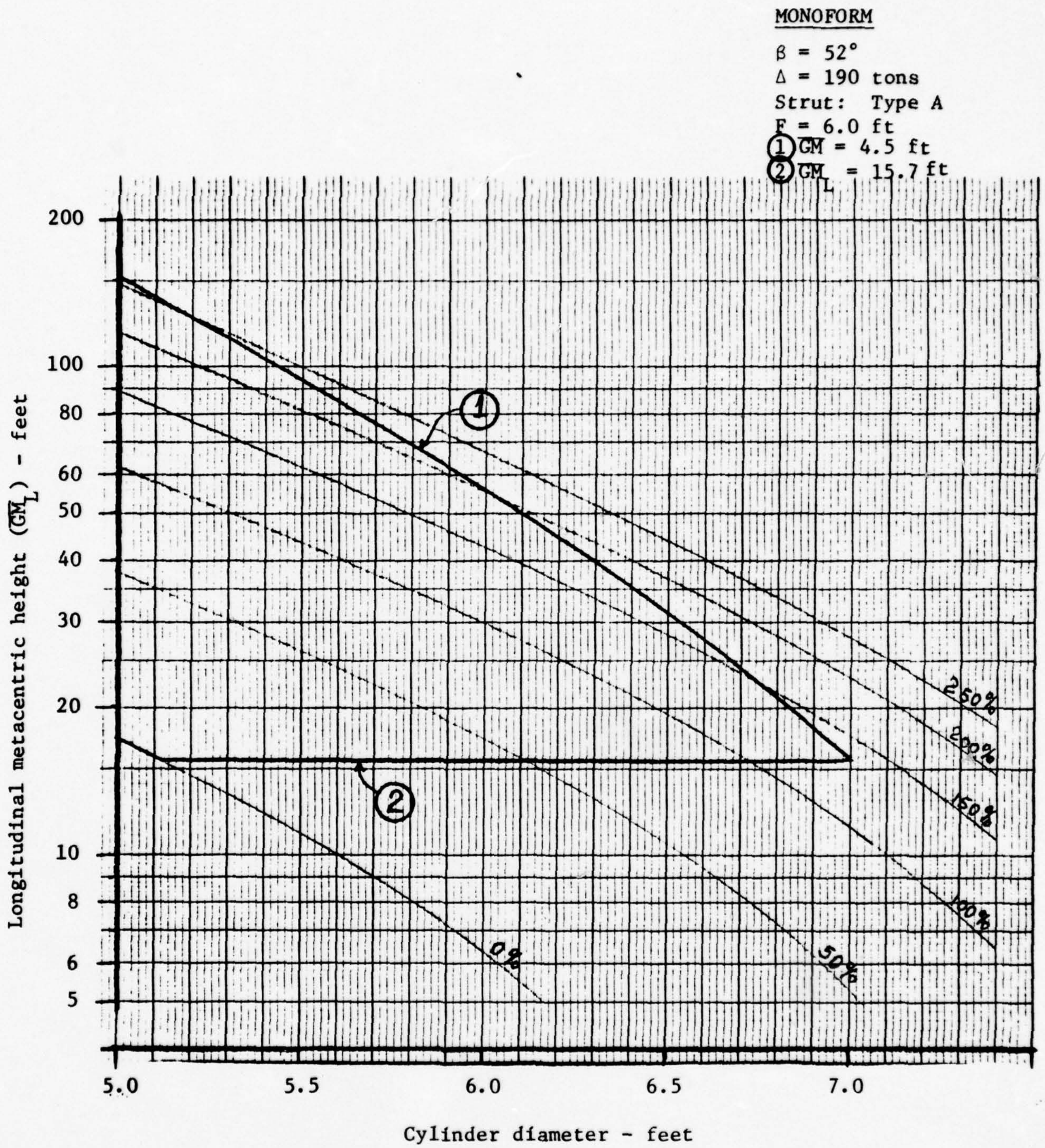

Figure B-5. Longitudinal metacenter chart for H/D = 2.0

MONOFORM

$\beta = 52°$
$\Delta = 190$ tons
Strut: Type A
F = 6.0 ft
1 $\overline{GM} = 4.5$ ft
2 $\overline{GM}_L = 15.7$ ft

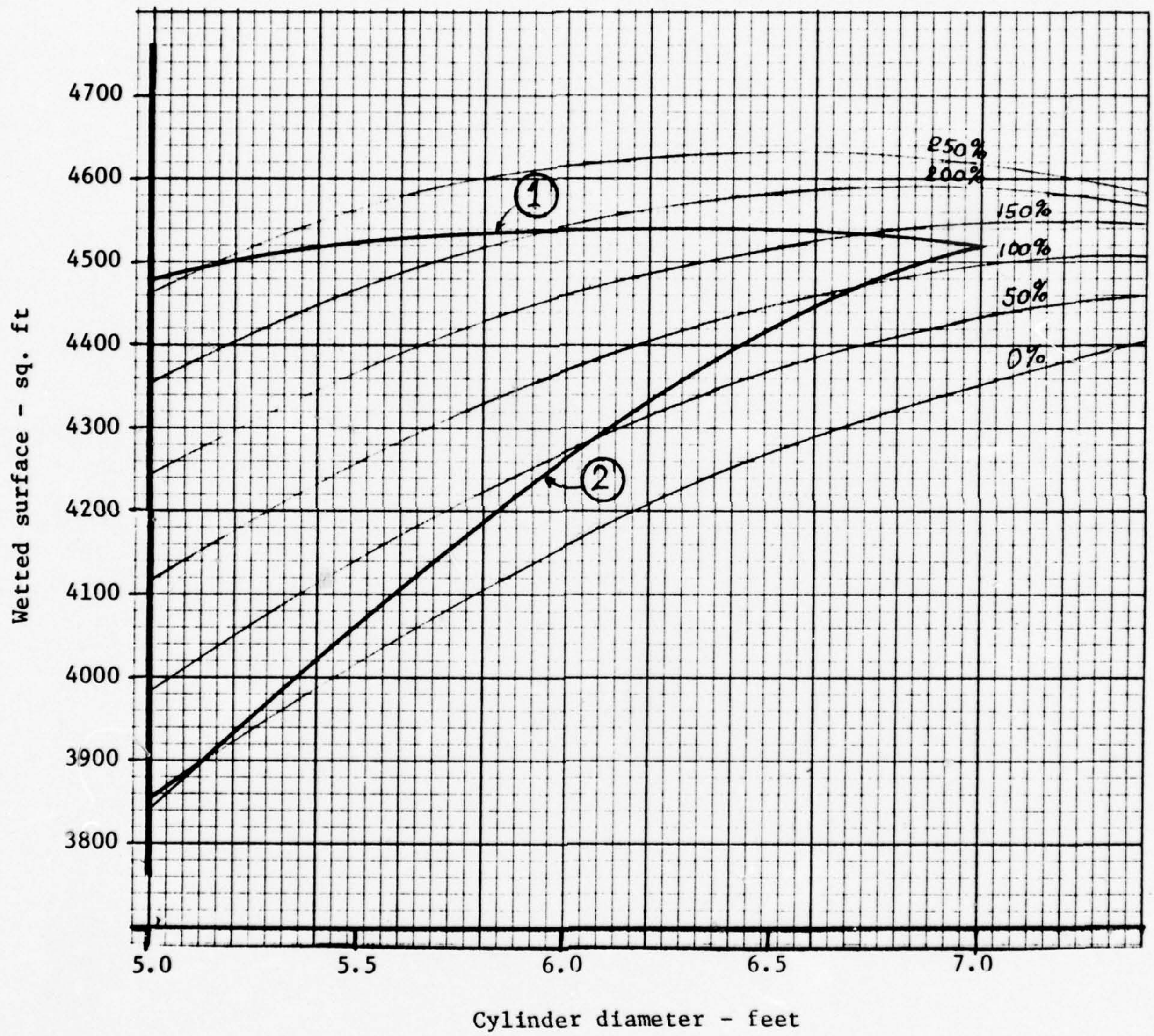

Figure B-6. Wetted surface chart for H/D = 2.0

MONOFORM

$\beta = 52°$
$\Delta = 190$ tons
Strut: Type A
F = 6.0 ft
1 $\overline{GM} = 4.5$ ft
2 $\overline{GM}_L = 15.7$ ft

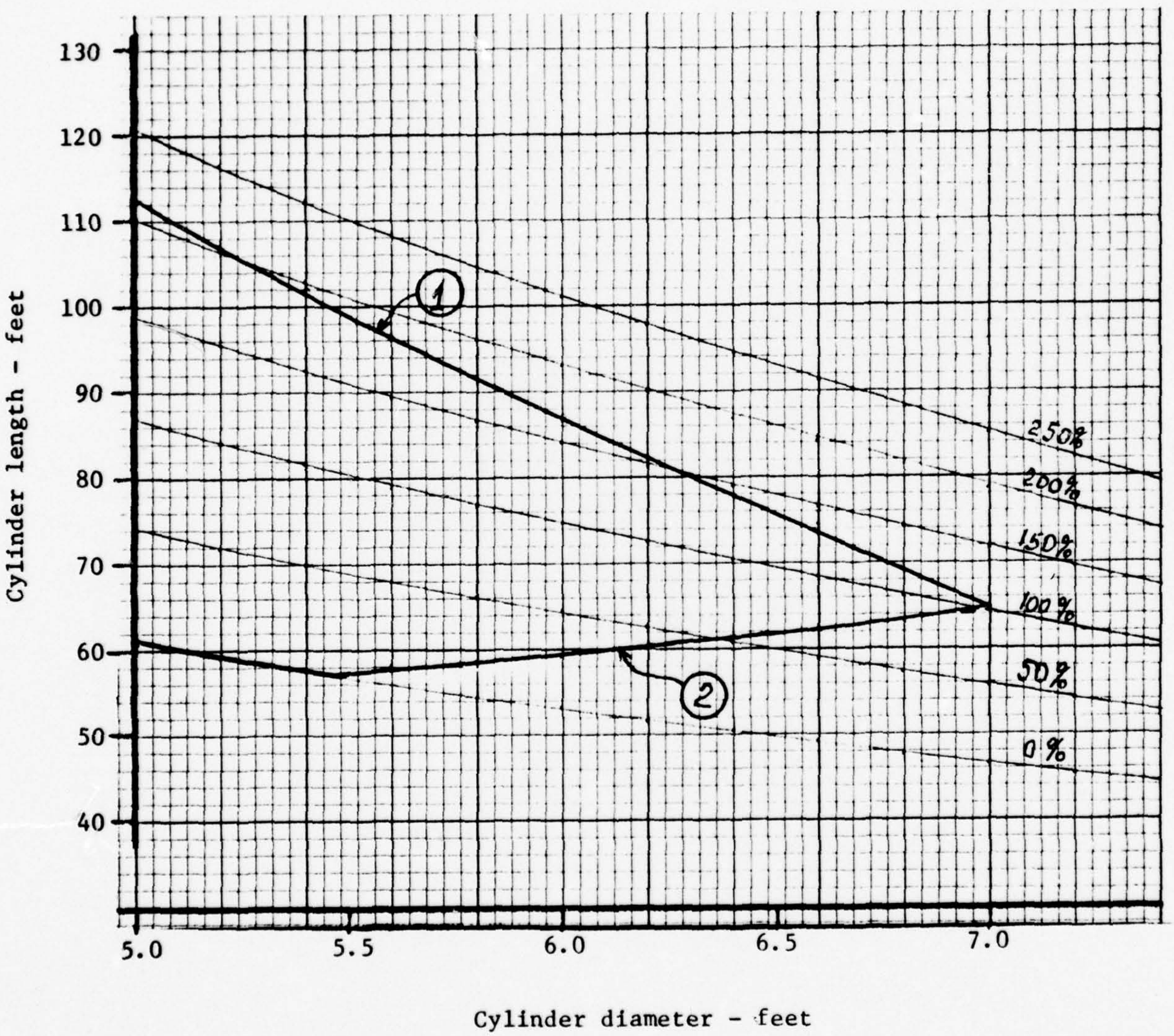

Figure B-7. Cylinder length chart for H/D = 1.85

MONOFORM

β = 52°
Δ = 190 tons
Strut: Type A
F = 6.0 ft
1 $\overline{GM}$ = 4.5 ft
2 $\overline{GM}_L$ = 15.7 ft

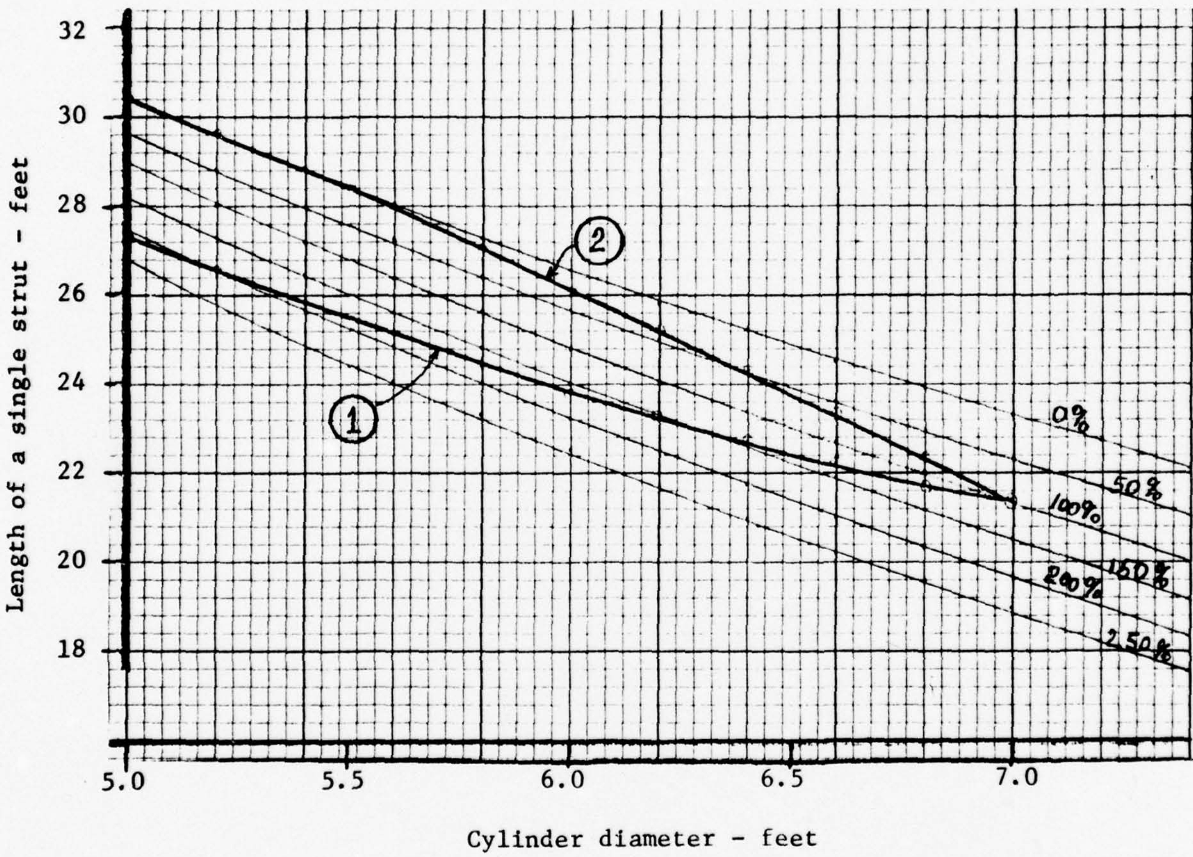

Figure B-8. Strut-length chart for H/D = 1.85

MONOFORM

β = 52°
Δ = 190 tons
Strut: Type A
F = 6.0 ft
1 $\overline{GM}$ = 4.5 ft
2 $\overline{GM}_L$ = 15.7 ft

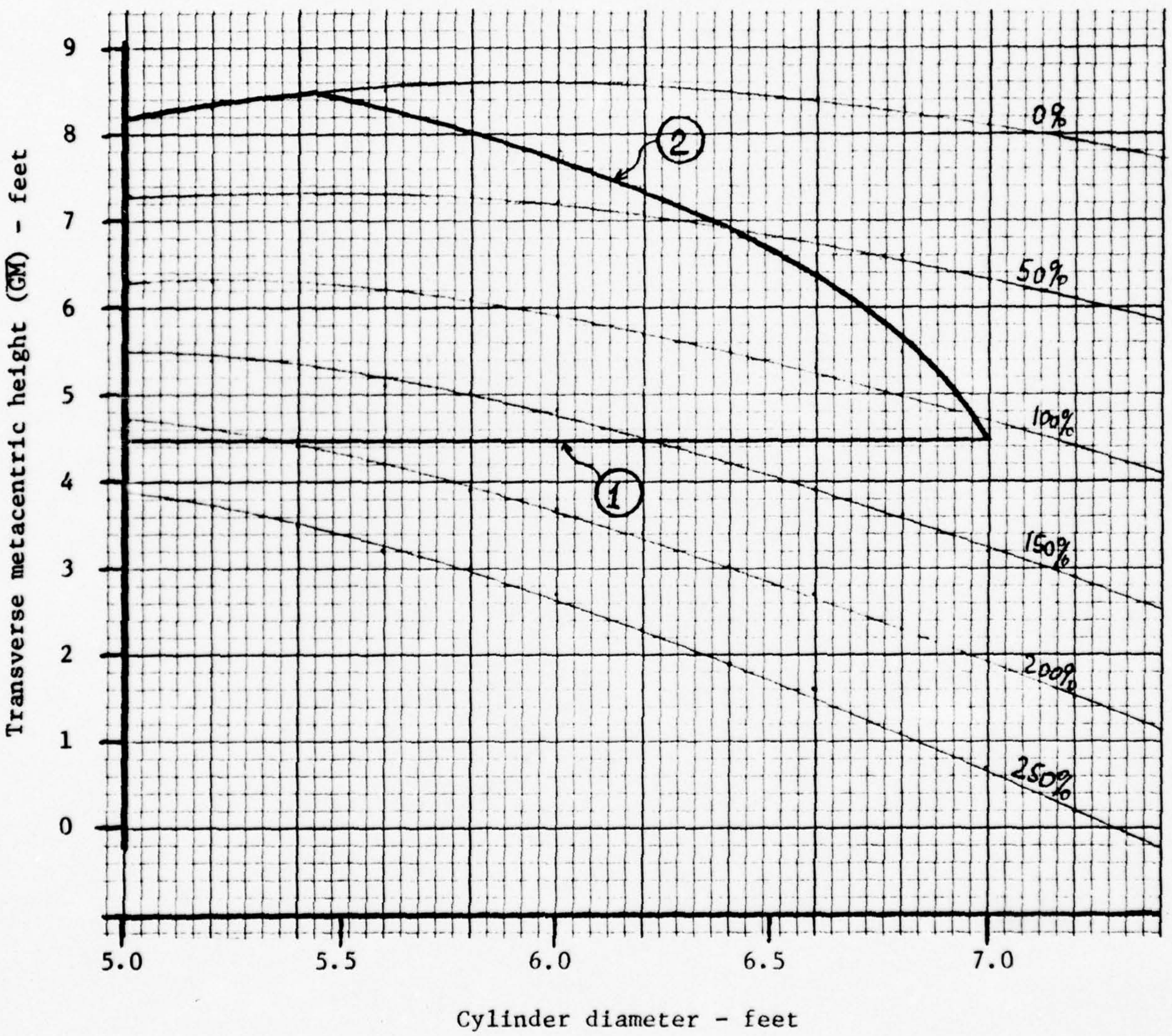

Figure B-9. Transverse metacenter chart for H/D = 1.85

MONOFORM

β = 52°
Δ = 190 tons
Strut: Type A
F = 6.0 ft
1 $\overline{GM}$ = 4.5 ft
2 $\overline{GM}_L$ = 15.7 ft

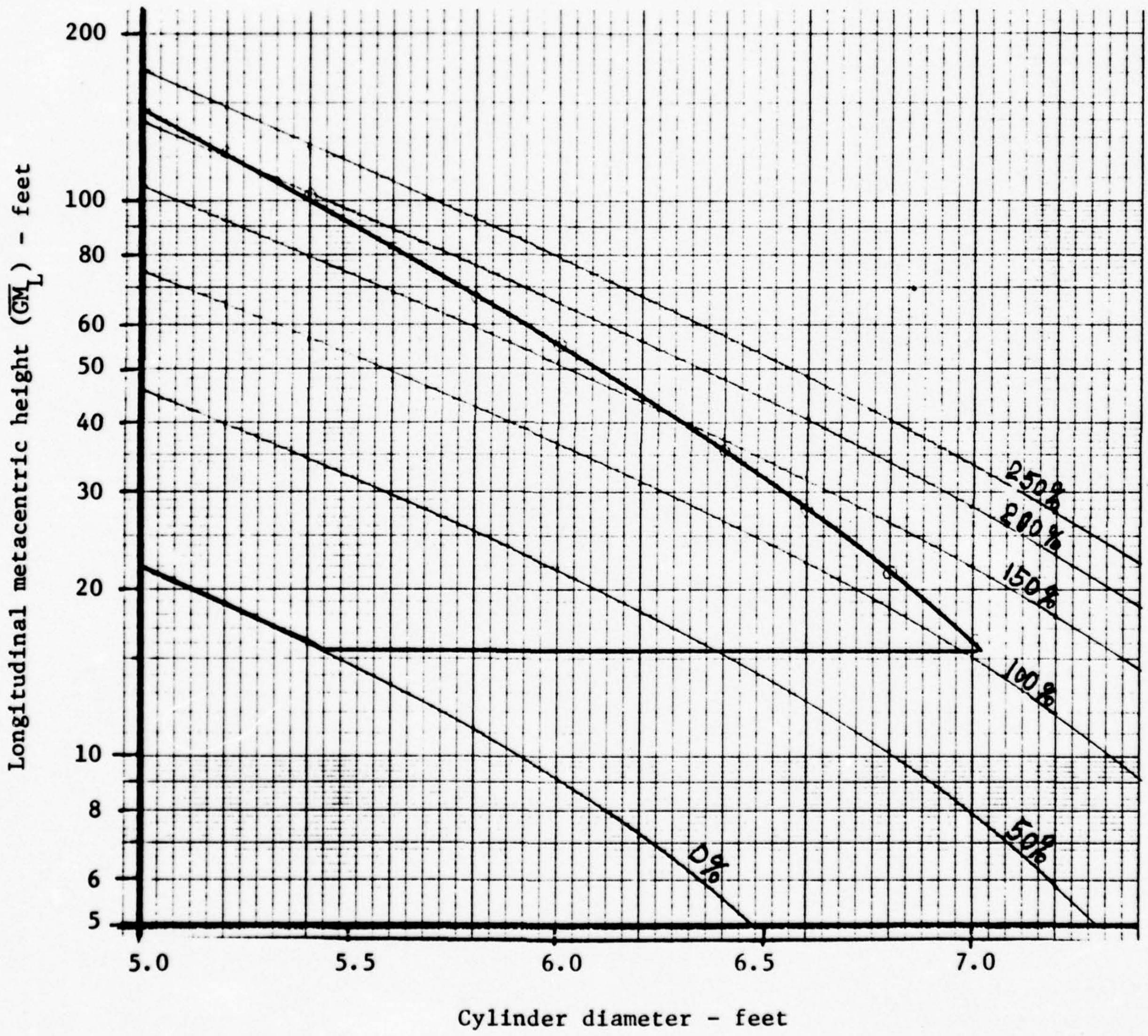

Figure B-10. Longitudinal metacenter chart for H/D = 1.85

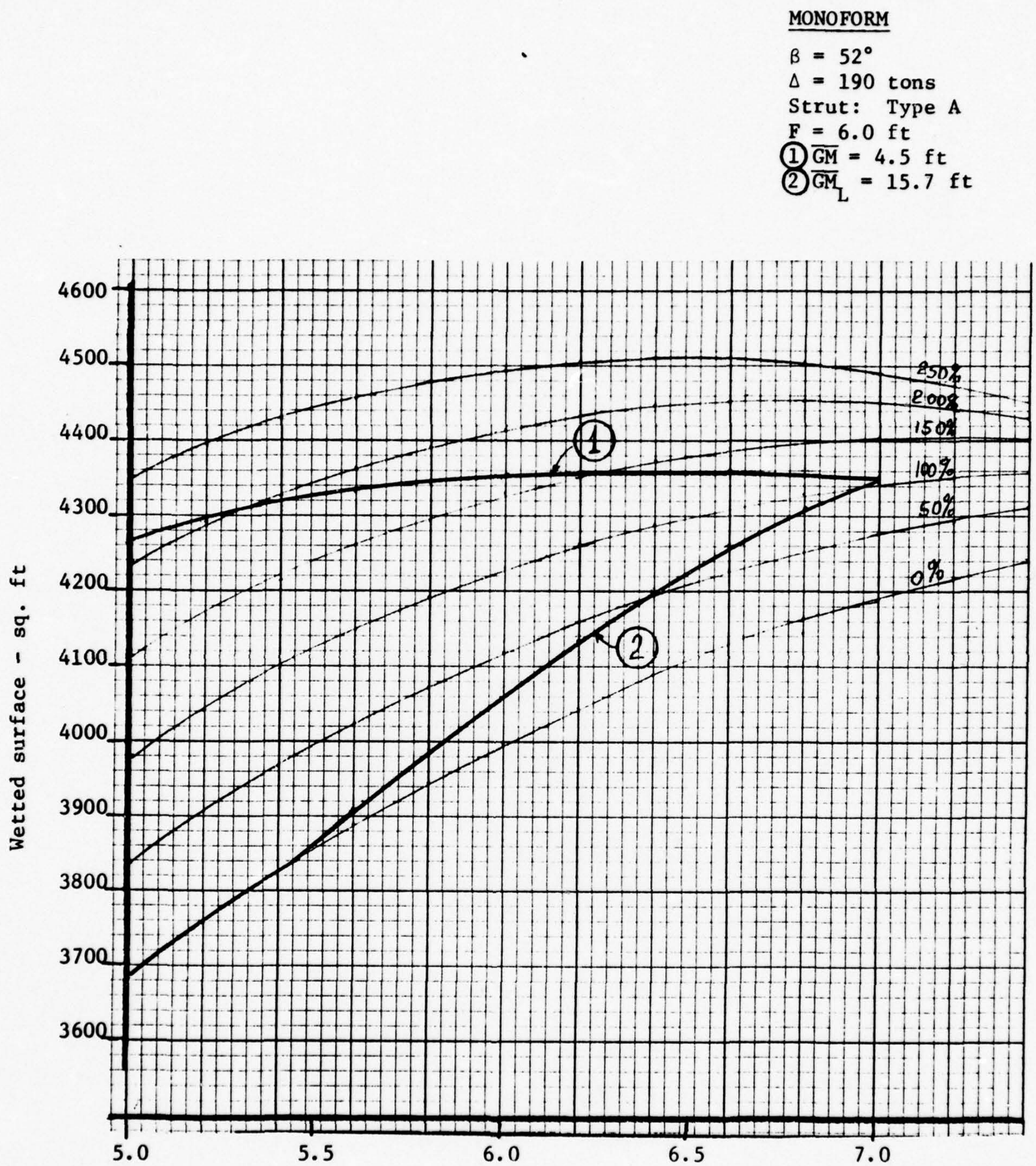

Figure B-11. Wetted surface chart for H/D = 1.85

<u>MONOFORM</u>

Δ = 190 tons
β = 52°
F = 6.0 ft.
Strut: Type A
(1) $\overline{GM}$ = 4.50 ft
(2) $\overline{GM}_L$ = 15.70 ft

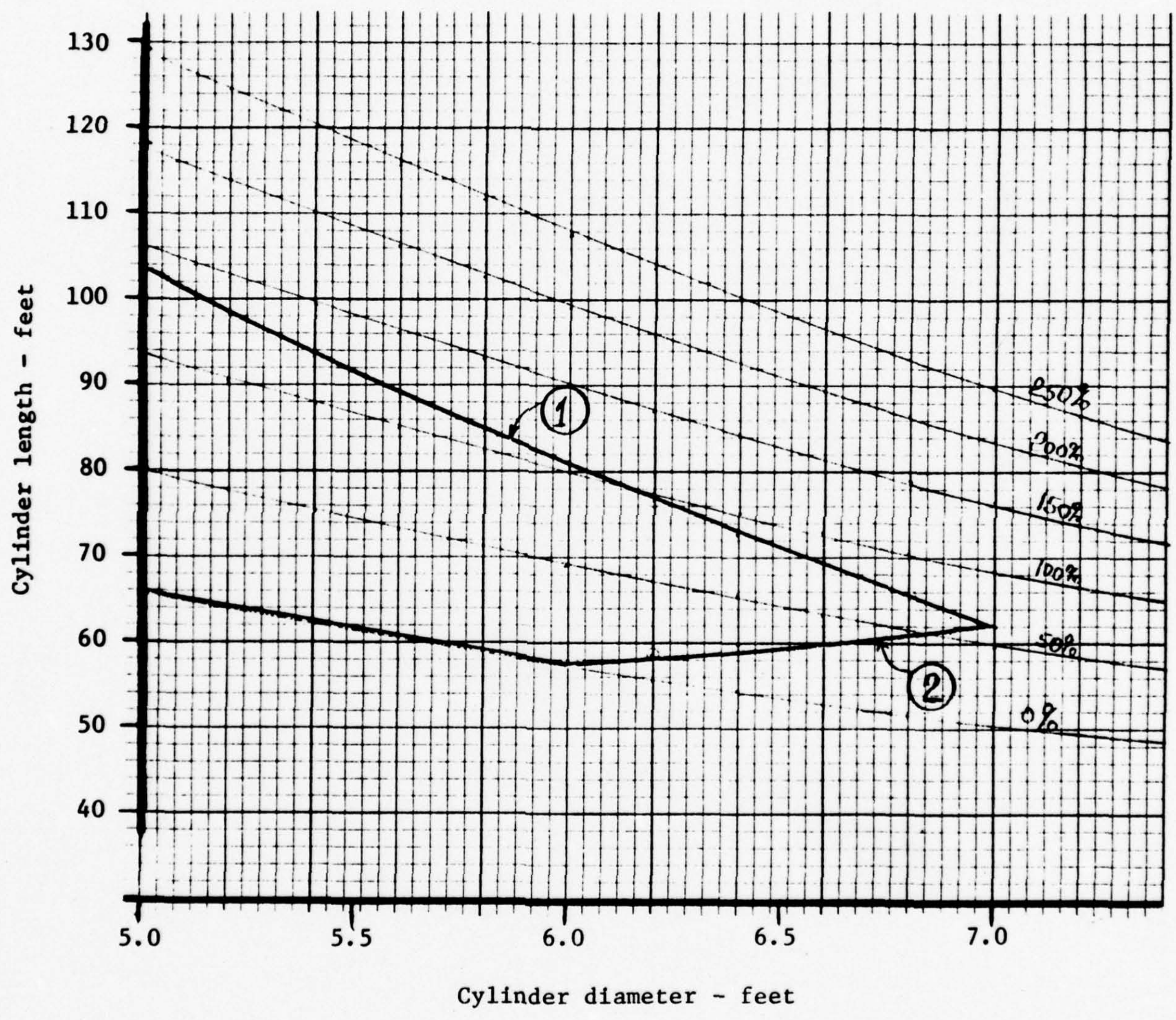

Figure B-12. Cylinder length chart for H/D = 1.60

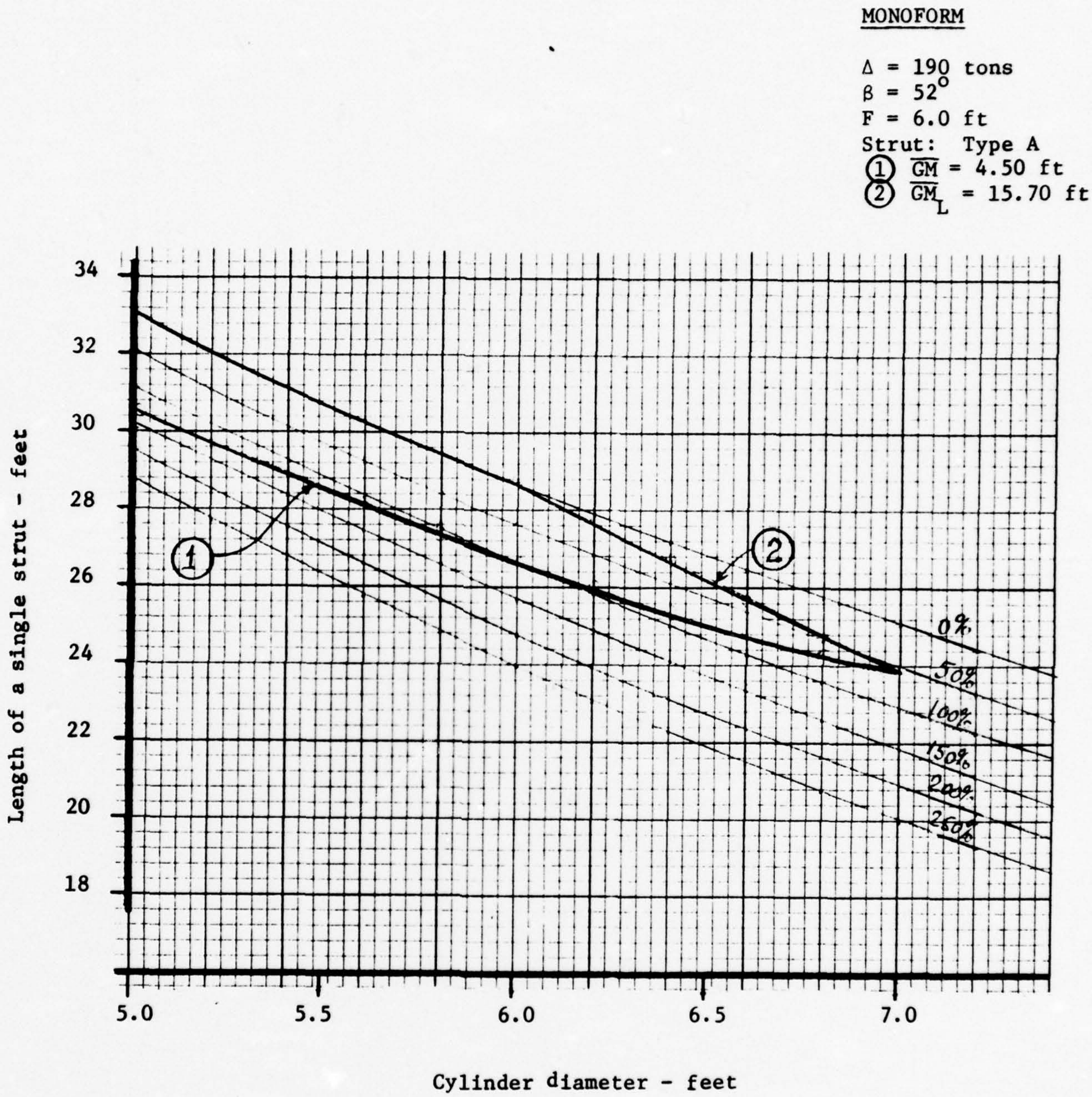

Figure B-13. Strut length chart for H/D = 1.60

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft.
Strut: Type A
(1) $\overline{GM}$ = 4.50 ft
(2) $\overline{GM}_L$ = 15.70 ft

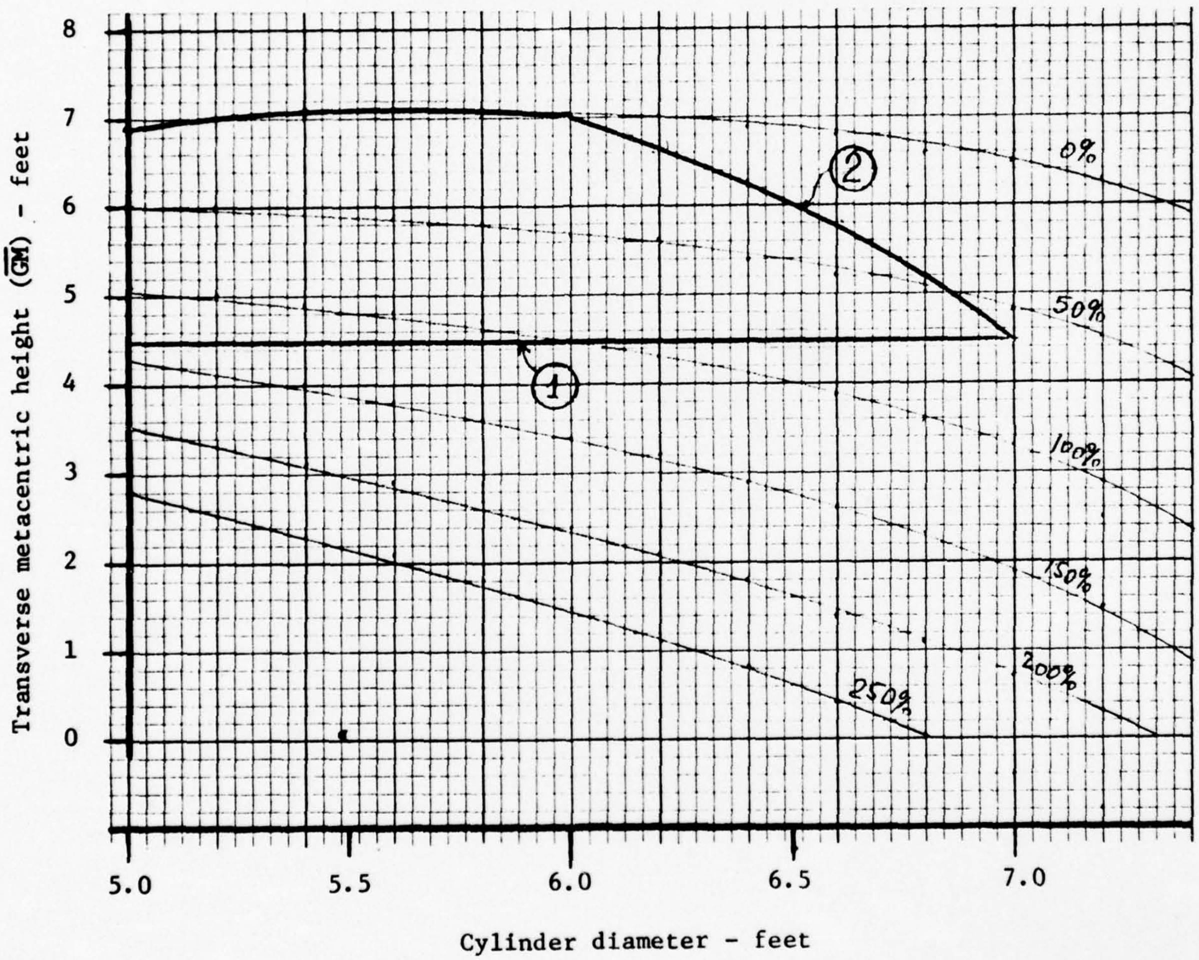

Figure B-14. Transverse metacenter chart for H/D = 1.60

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft.
Strut: Type A
① $\overline{GM}$ = 4.50 ft
② $\overline{GM}_L$ = 15.70 ft

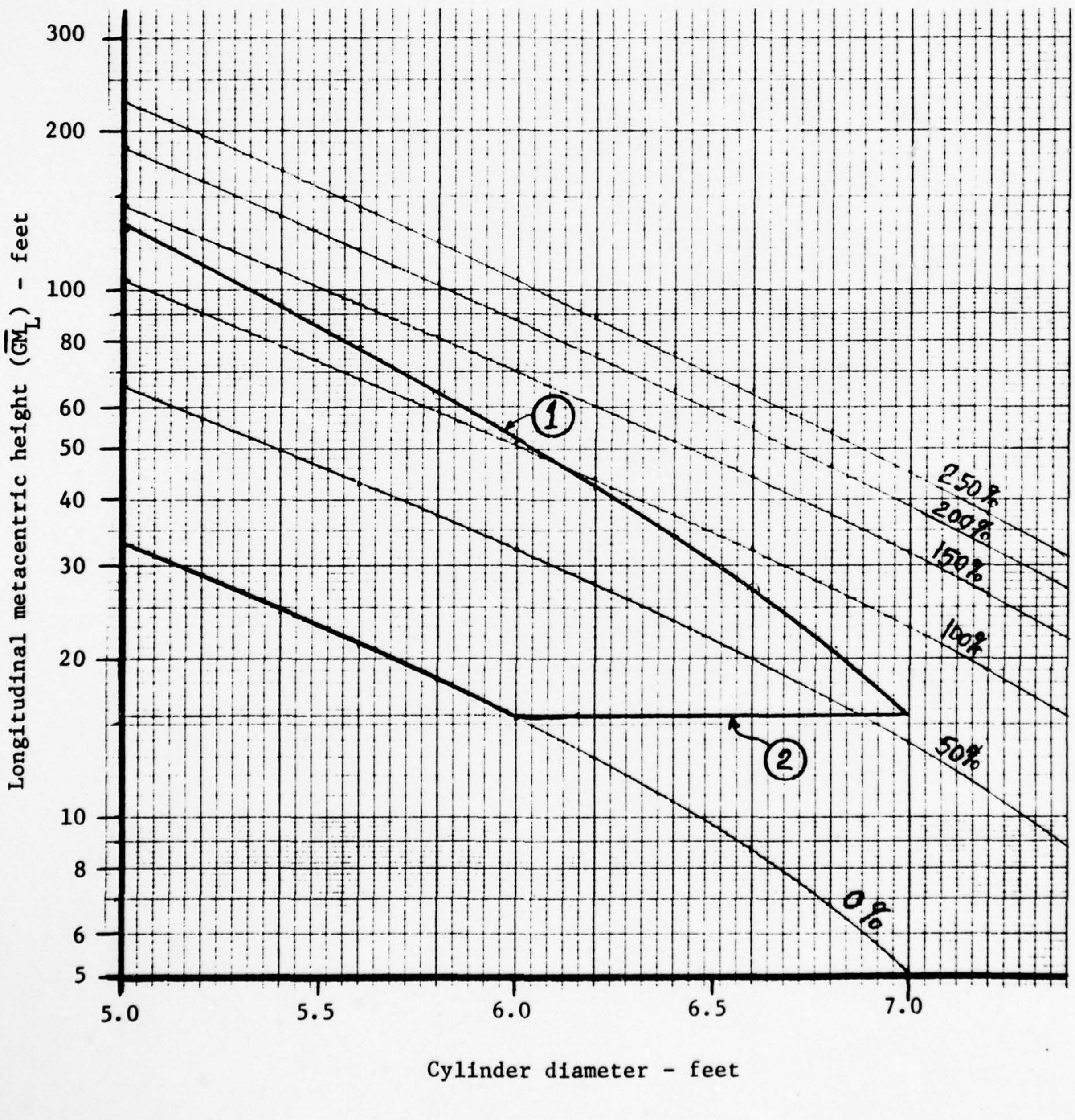

Figure B-15. Longitudinal metacenter chart for H/D = 1.60

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
① $\overline{GM}$ = 4.50 ft
② $\overline{GM}_L$ = 15.70 ft

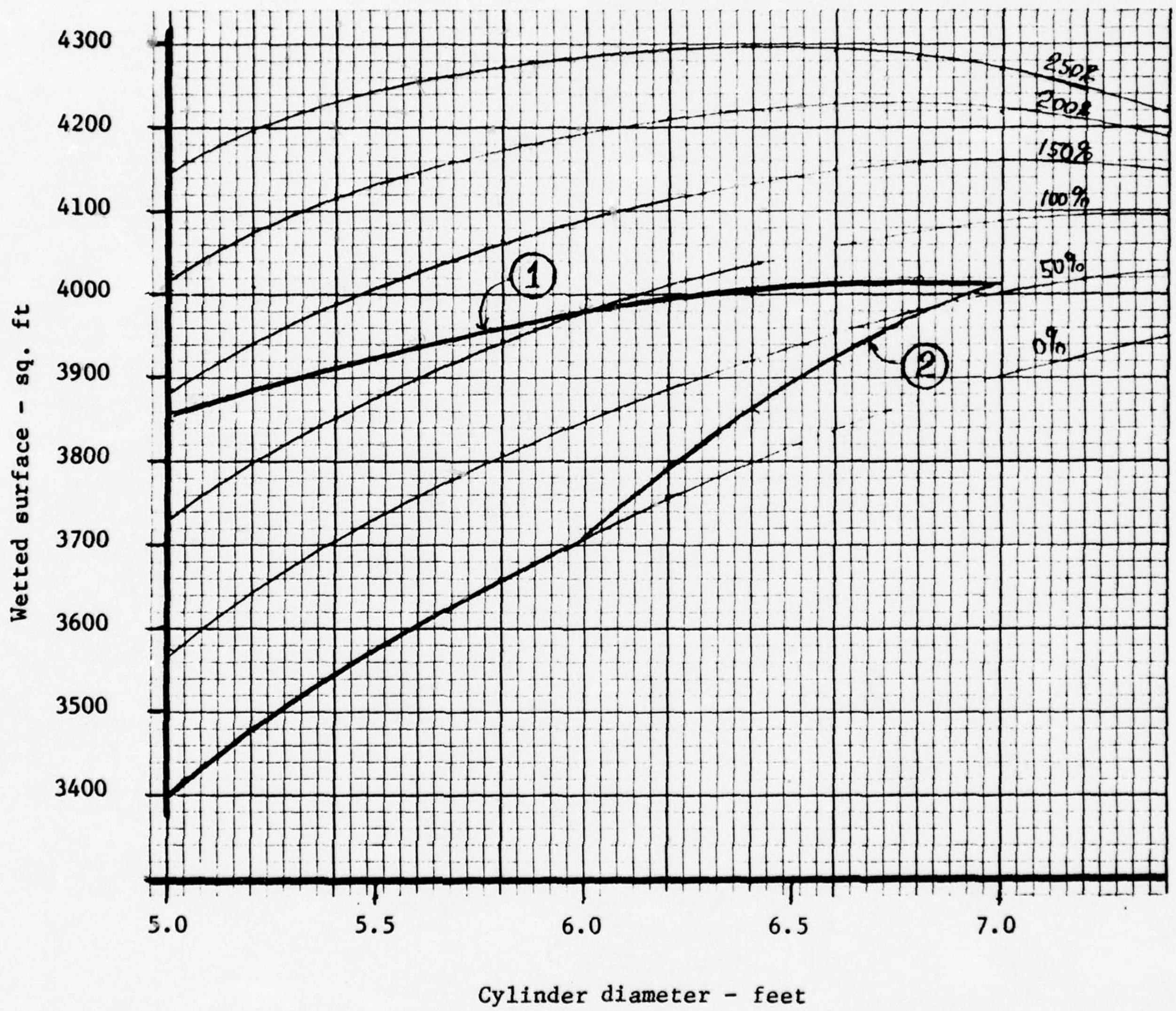

Figure B-16. Wetted surface chart for H/D = 1.60

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
(1) $\overline{GM}$ = 4.50 ft
(2) $\overline{GM}_L$ = 15.7 ft

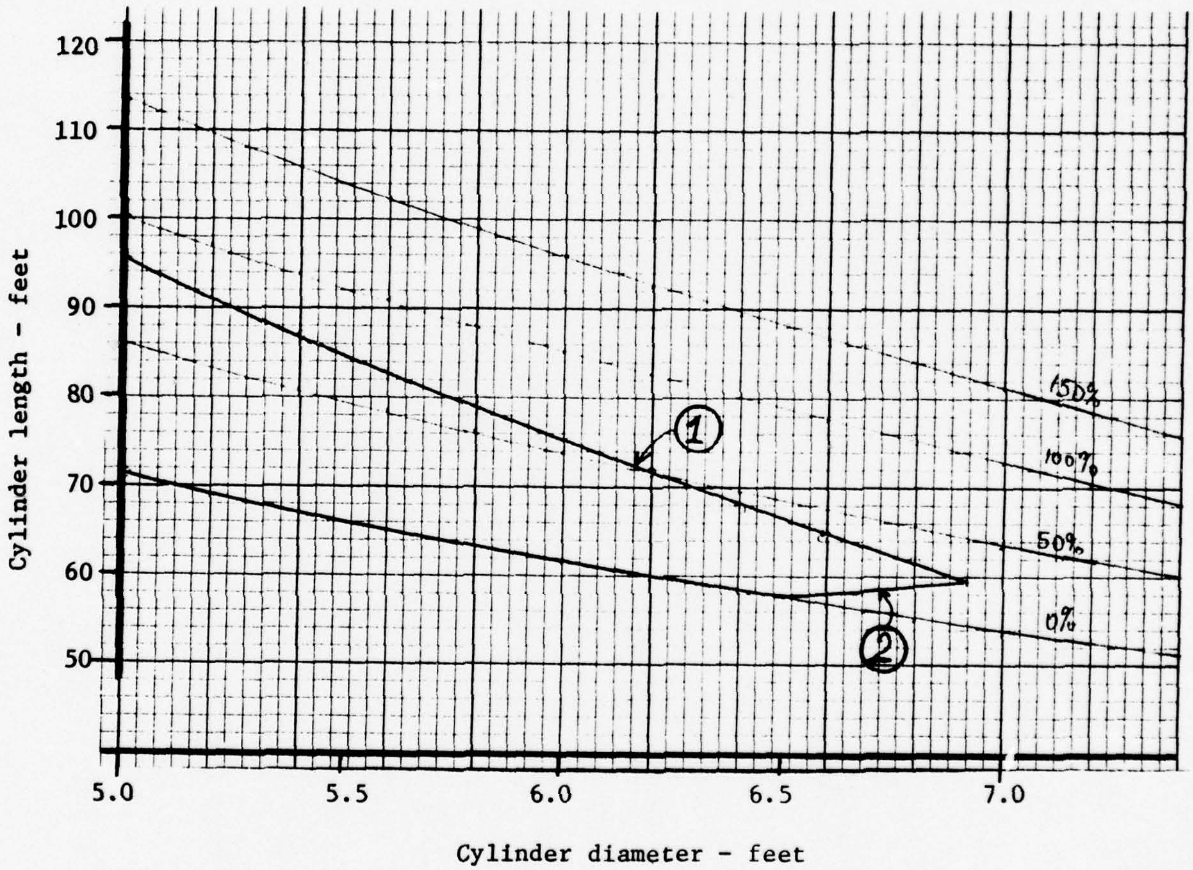

Figure B-17. Cylinder length chart for H/D = 1.40

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
(1) $\overline{GM}$ = 4.50 ft
(2) $\overline{GM}_L$ = 15.7 ft

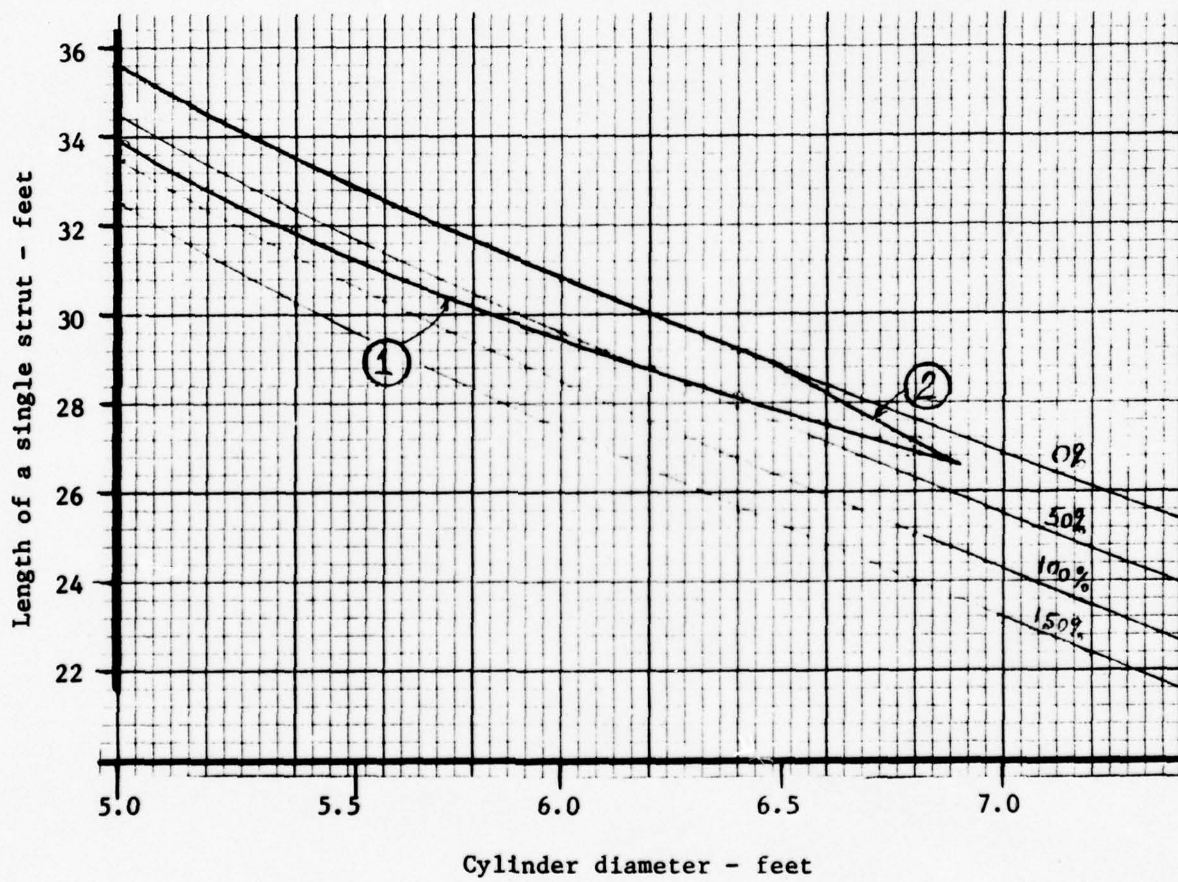

Figure B-18. Strut length chart for H/D = 1.40

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
1 $\overline{GM}$ = 4.50 ft
2 $\overline{GM}_L$ = 15.7 ft

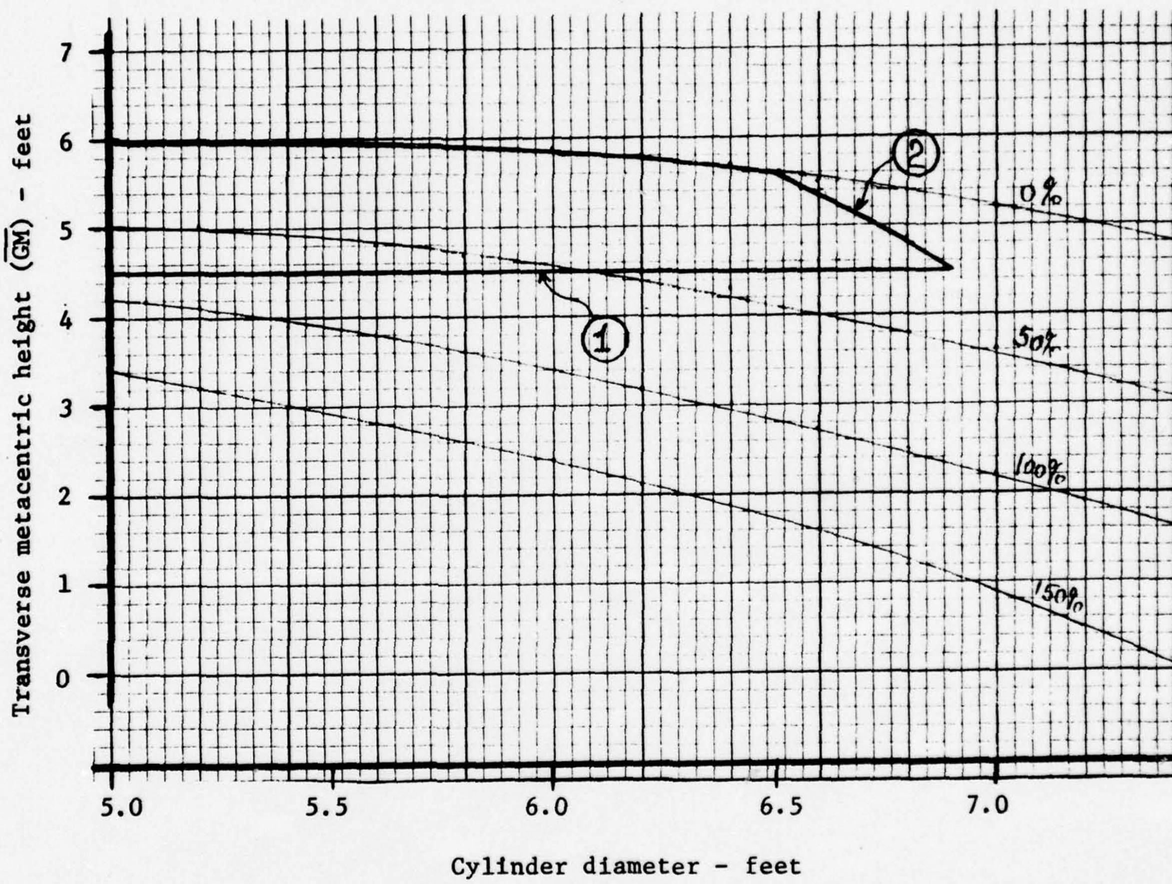

Figure B-19. Transverse metacenter chart for H/D = 1.40

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft.
Strut: Type A
1 $\overline{GM}$ = 4.50 ft
2 $\overline{GM}_L$ = 15.70 ft

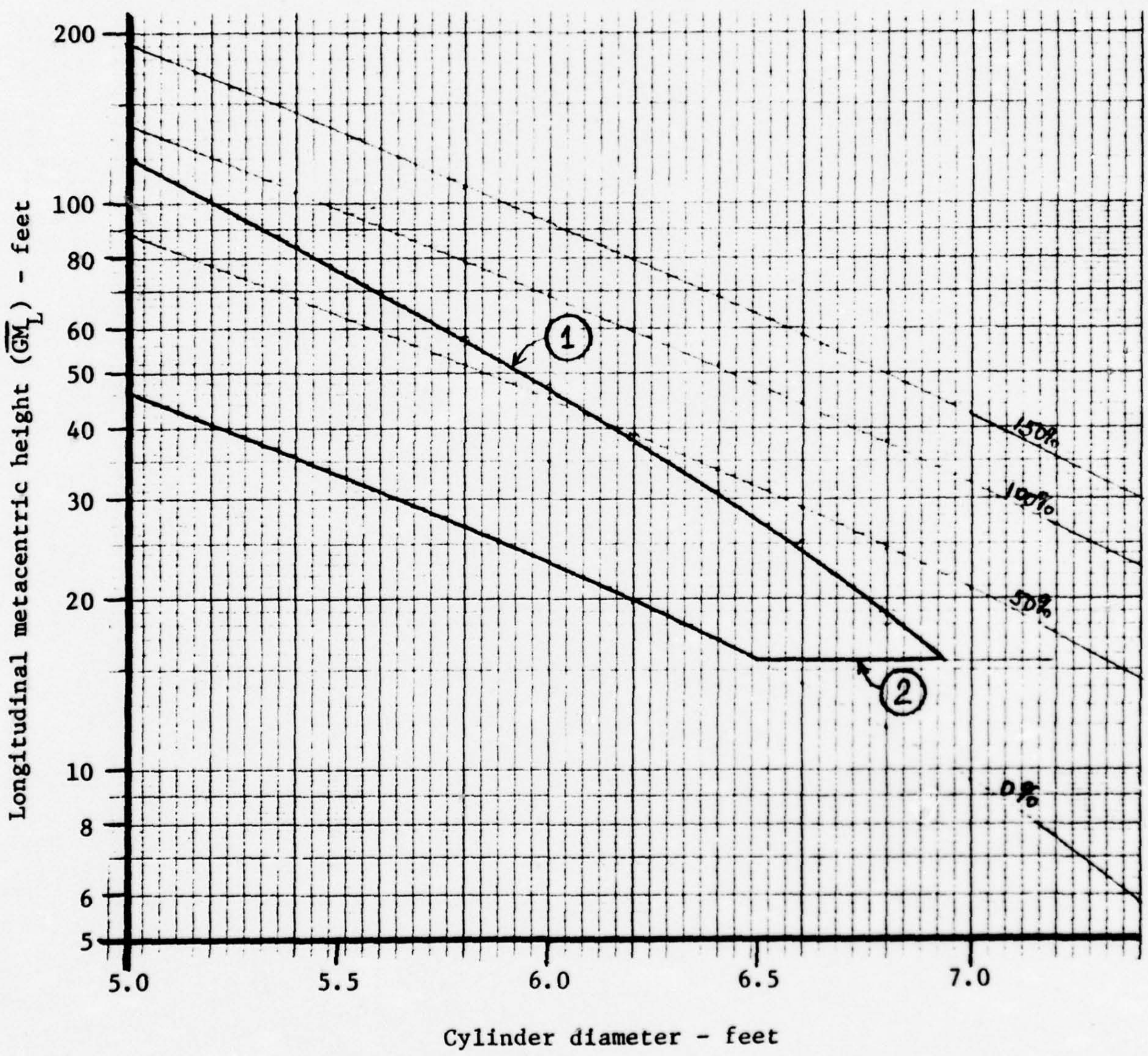

Figure B-20. Longitudinal metacenter chart for H/D = 1.40

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
(1) $\overline{GM}$ = 4.50 ft
(2) $\overline{GM}_L$ = 15.7 ft

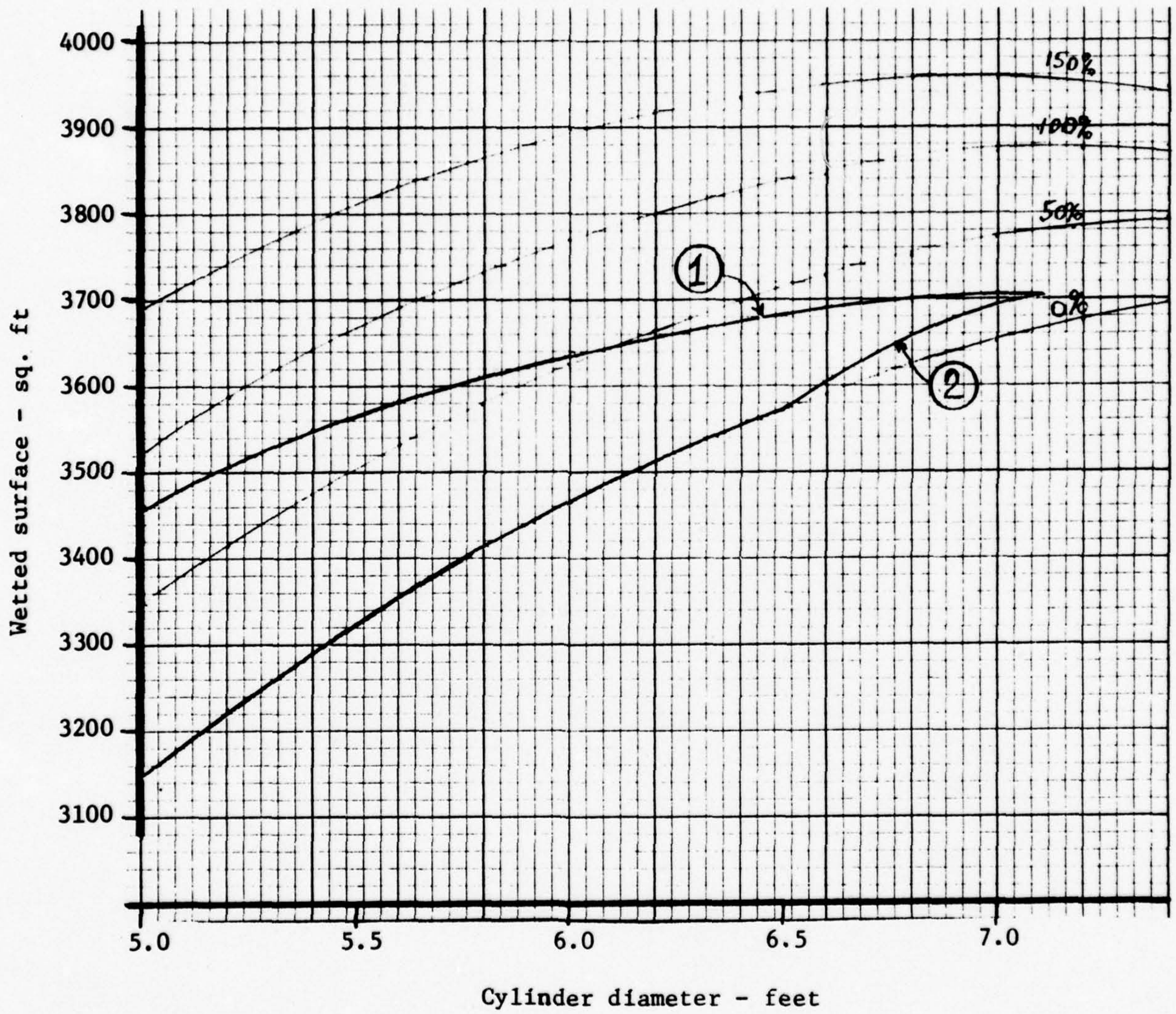

Figure B-21. Wetted surface chart for H/D = 1.40

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
Type B

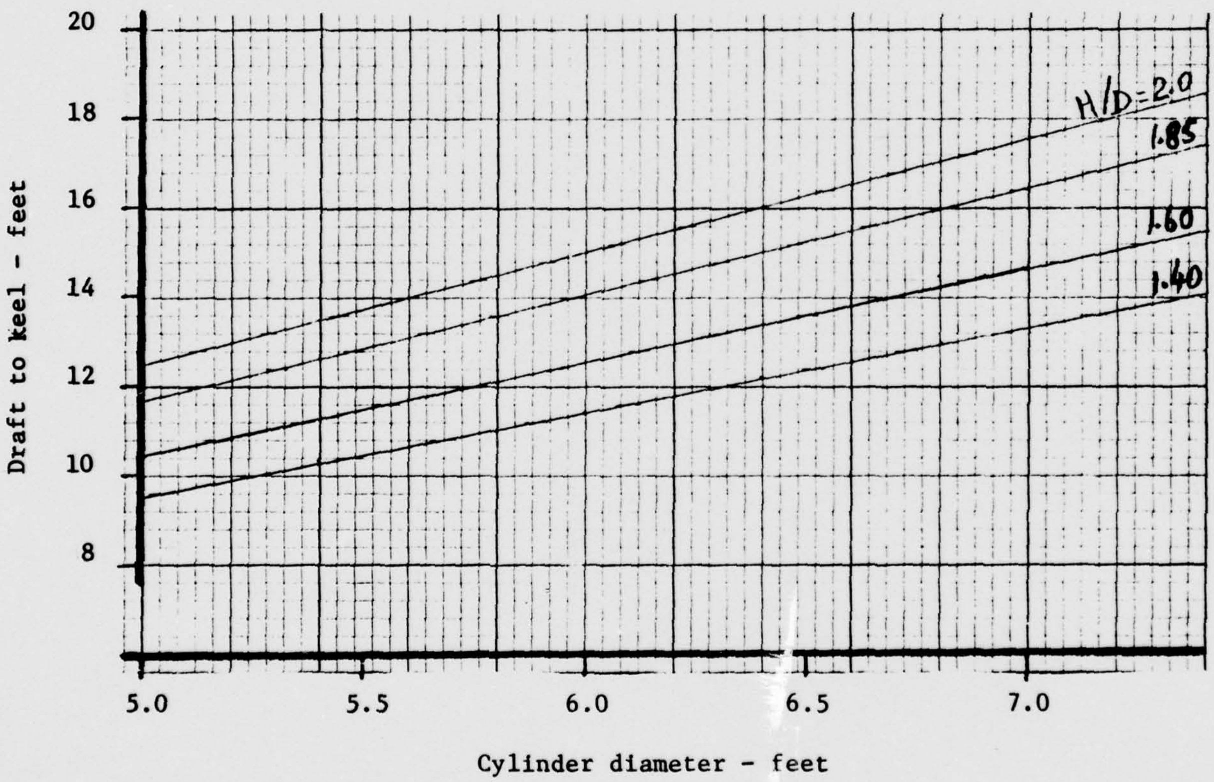

Figure B-22. Variations in draft

MONOFORM

Δ = 190 tons
β = 52°
F = 6.0 ft
Strut: Type A
Type B

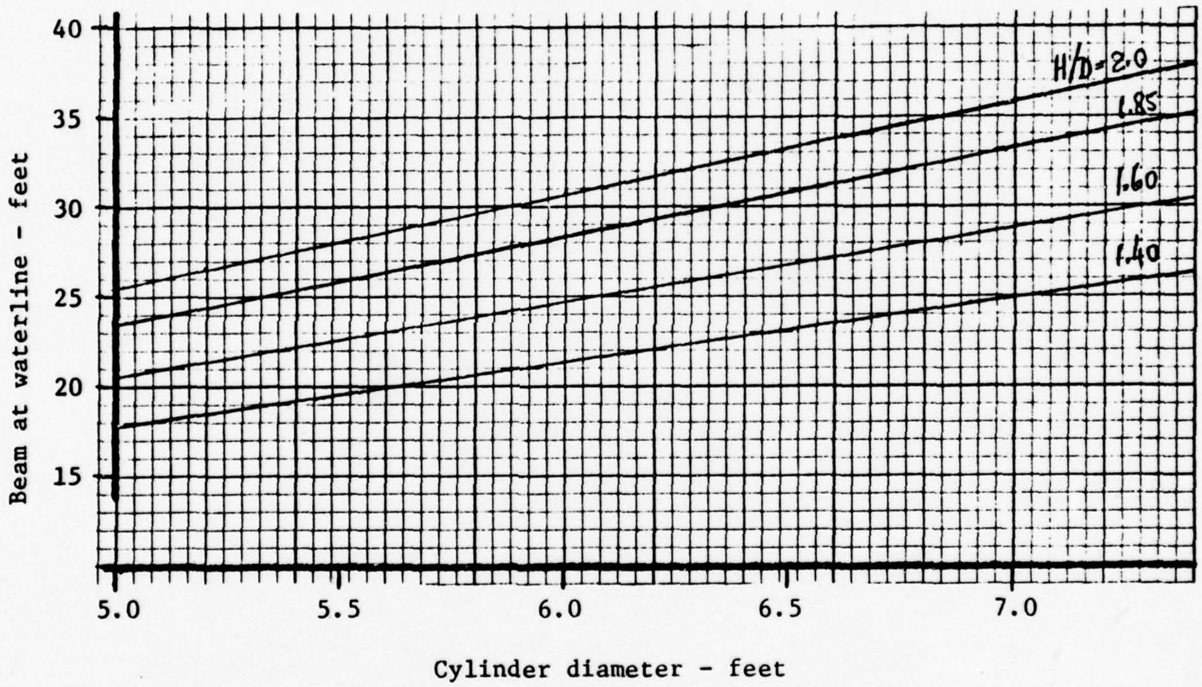

Figure B-23. Variations in waterline beam

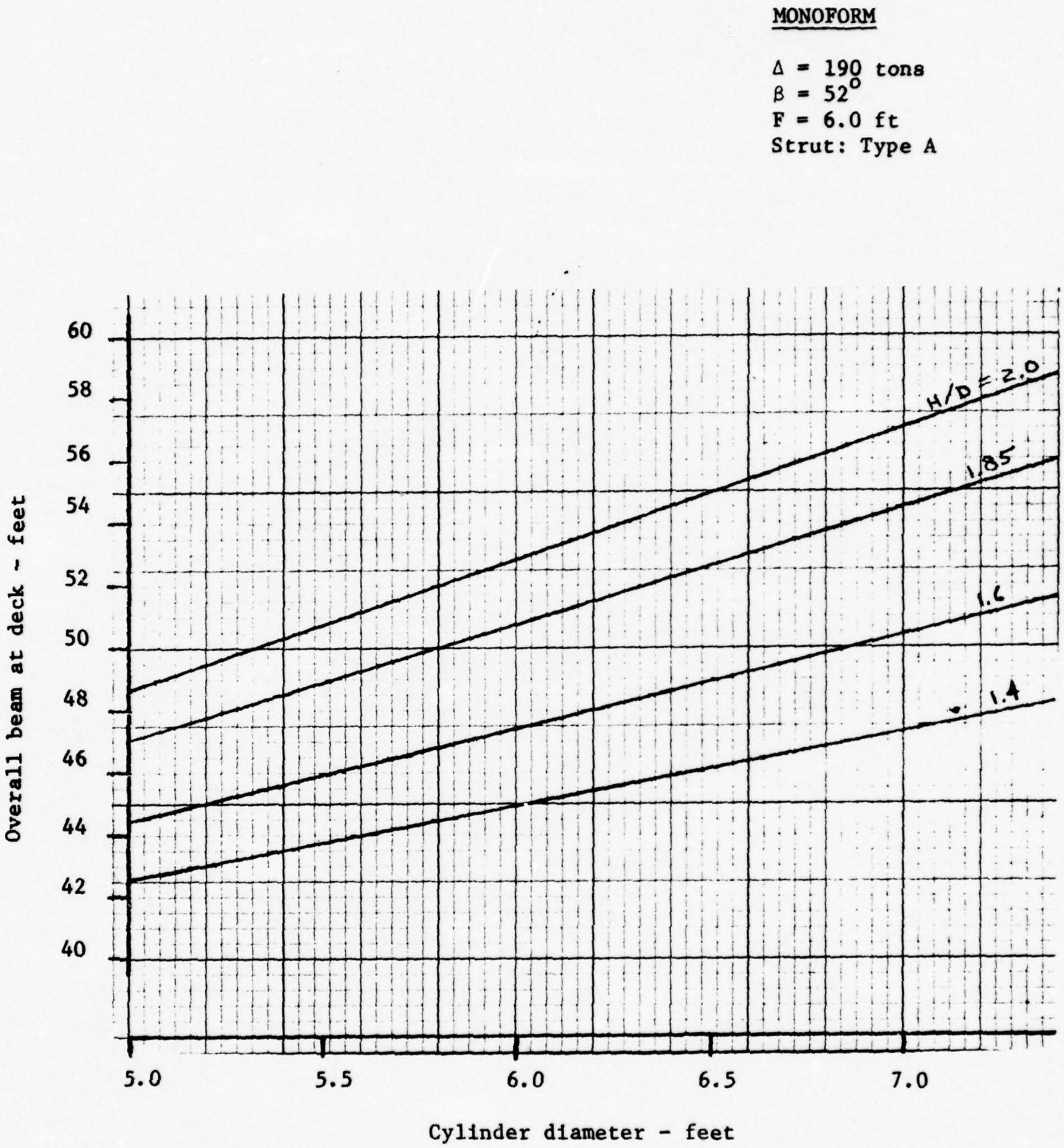

Figure B-24. Variations in beam at deck

STRUT TYPE-B

Description of Model B

The effort to further reduce the wetted surface of the inclined struts of the MONOFORM hull lead to a new strut design, which was named Type B. This strut differs from Type A in that the Type B strut has a variable cross section as opposed to the constant lenticular cross section of type A struts.

The new strut is designed to have a 17% thick lenticular cross section at the waterline same as that of type A. The length of the strut B is varying with elevation, for it is tapered as shown in the profile view of figure 25. The length of the strut at the intersection with the cylinder is half of its length at the waterline. The taper in the profile is linear and continues up to the deck level. Thus, the strut is longest at the top and shortest at its base.

As pictured in the cross sectional view, the thickness of the strut does not change with elevation, it retains the same value (17% of the strut length at the waterline) throughout its extent. The reason for the constant thickness is the desire to provide easy access to the underwater cylinder through the struts. It was stipulated that if a 17% lenticular type A strut had adequate opening to permit necessary access to the lower hull, a tapered strut with the same constant thickness would accomplish the same task.

The cross section of the strut B changes with elevation. The strut is lenticular only between the deck and the 80% draft mark. The strut at the base has a streamlined shape with a blunt nose and a pointed trailing edge. This section is of the same thickness as the section at the waterline but only half as long, thus the profile at the base has a thickness to chord length ratio of 34%. The taper is shown in figure 25 to be the same fore and aft of the midstrut section. This, however, can be changed if the maximum thickness at the base is to be moved from the present 50% location. (The maximum thickness

NOMENCLATURE:

B = overall beam at deck

B_{WL} = beam at waterline (nominal)

D = cylinder diameter

F = freeboard

G = center of gravity

H = draft to cylinder centerline

L = overall length of deck

L_B = strut length at strut base

L_C = cylinder length (nominal)

L_{max} = overall length of hull

L_{SWL} = strut length at waterline

T_s = strut thickness

β = strut angle

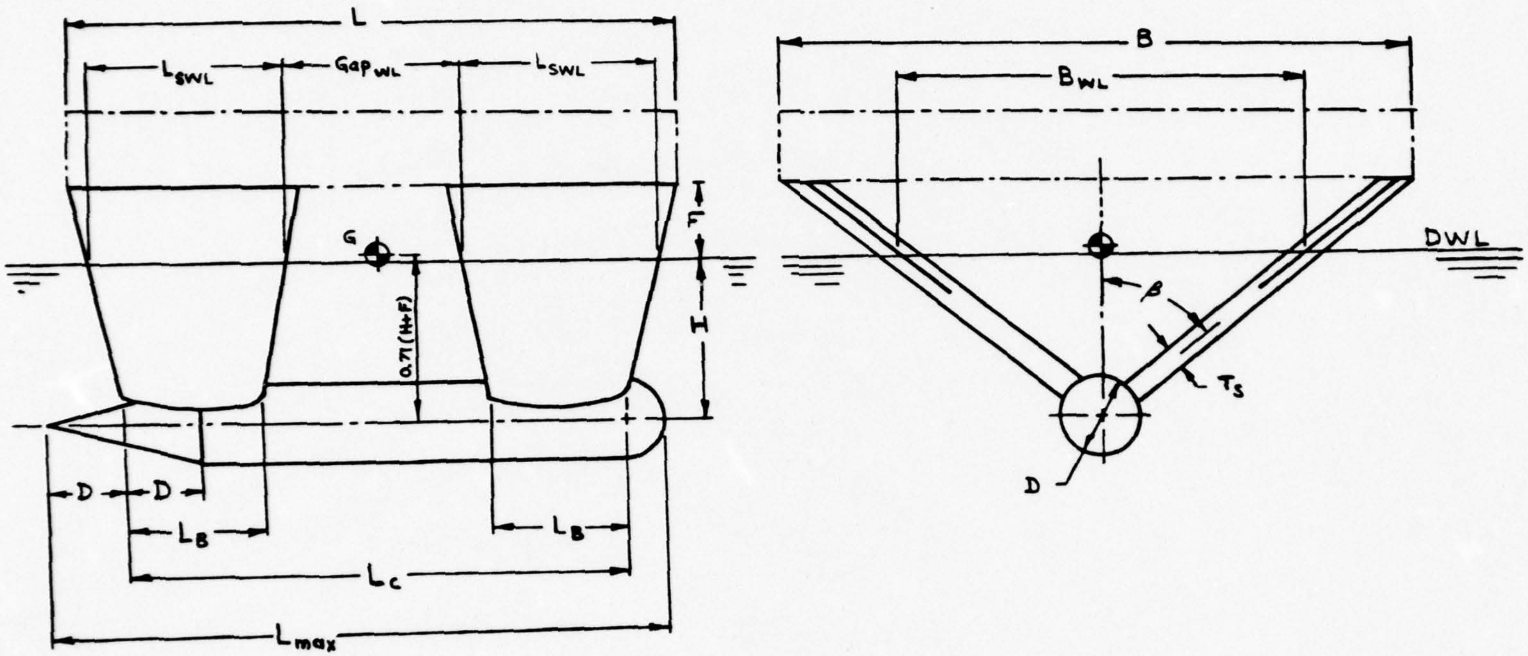

Figure B-25. Geometry and Nomenclature for Parametric Analysis; Strut Type B

of streamlined sections are usually located at about 30% of the chord length from the leading edge). The optimum configuration of the streamlined strut will be found during hydrodynamic analysis and/or during model tests.

After the new strut dimensions were introduced into the computer model, the computations, described in the strut A section, were repeated. The graphical representations of the results are shown in figures 26 through 47. These figures are placed at the end of this section to permit easier reading of the report.

Design Charts for Strut Type B

The results of the parametric analysis of the MONOFORM hull with type B struts are presented graphically in figures 26 through 47. The organization of the charts and the range of the parameters are the same as had been described for strut A, therefore, they are not repeated here. There are a few exceptions, however. The total draft and the beam at the waterline are independent of strut configuration; therefore, figures 22 and 23 are valid for both models, A and B. Another exception is the length of the deck. For model A it is not shown on separate charts, because it is shorter than the underwater hull, although prudent design practice calls for some deck overhang to protect the underwater hull from damage at docking. For model B, because of the tapered struts, the deck is longer than the underwater hull. The deck length of model B is shown in figure 47 as a function of cylinder diameter and draft ratio. It should be noted also that the gap for strut B is defined at the waterline since the gap is changing with elevation. The gap for strut A did not vary with elevation, therefore, such a distinction there was not necessary. Figures 46 and 47 are based on 100% gap at the waterline.

For easier comparison of the characteristics of model B with the characteristics of model A the same set of data listed in Table 2 are tabulated in Table 3

for model B. It should be recalled that the data refers to a MONOFORM hull of 190 tons displacement, 1.85 draft ratio, 6 ft free-board, 17% thick lenticular strut (at the waterline), 52° strut angle, and 100% strut gap at the waterline.

Table B-3

MONOFORM Characteristics for 100% Strut Gap, H/D = 1.85, Strut B

	D = 5.0 ft	D = 6.0 ft	D = 7.0 ft	SSP(D = 6.5 ft)
$L_{cylinder}$	81.8 ft	70.4 ft	60.9 ft	55 ft
L_{max} (hull)	89.3 ft	79.4 ft	71.4 ft	74 ft
L (at deck)	110.7 ft	93.6 ft	79.8 ft	77 ft
L_{strut} (at WL)	32.7 ft	28.2 ft	24.3 ft	24 ft
B_{WL}	23.7 ft	28.4 ft	33.2 ft	40.0 ft
B (at deck)	48.1 ft	51.6 ft	55.3 ft	45.0 ft
Draft to keel	11.8 ft	14.1 ft	16.4 ft	15.2 ft
$\overline{GM}$	10.4 ft	10.4 ft	9.6 ft	4.5 ft
$\overline{GM}_L$	126.0 ft	62.5 ft	32.0 ft	15.7 ft
S_w	3650 ft^2	3840 ft^2	3910 ft^2	4830 ft^2

A comparison of data in Table 2 and Table 3 indicates that model B is longer, beamier, and more stable than the corresponding model A. In addition, the wetted surface for the 5 ft diameter version is 8.3% smaller for model B than for model A; the surface reduction is 9.2% for the 6 ft and 9.9% for the 7 ft version.

In particular, the 6 ft diameter version has a wetted surface of 3840 ft^2 which is 390 ft^2 less than the surface of model A. There is a significant increase in stability: transverse $\overline{GM}$ is almost doubled from 5.9 ft to 10.4 ft, while the longitudinal metacentric height increased from 37 ft to 62.5 ft. There is a 10 ft increase in the length of the deck from 84 to 94 ft and a slight increase in the beam at deck from 50.7 to 51.6 ft. The increase in deck area raises the question of structural weight again. The weight, however, can not be evaluated without a relatively detailed structural analysis. There is, however, one way to keep the length of the deck of model B within reasonable limits. The tapering of the leading edge of the forward strut and the tapering of the trailing edge of the aft strut could be terminated at the waterline (or shortly above it). The use of these struts could reduce the deck length (in the limit) to 3 times the length of one strut at the waterline (in the case of 100% gap). Using broken tapered struts in the above example would require a deck length of only 85 ft, just 1 foot longer than the deck of model A.

A comparison of the 6 ft diameter model B with the SSP is very favorable in every respect, with the exception of the possible structural weight disadvantages due to the increased deck area. (Incidentally, an increase in deck area might even be desirable from the point of view of the ship's mission). If desired, the length of the deck can be reduced by modifying the strut's profile above the waterline, as was mentioned earlier.

MONOFORM

$\beta = 52^{o}$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

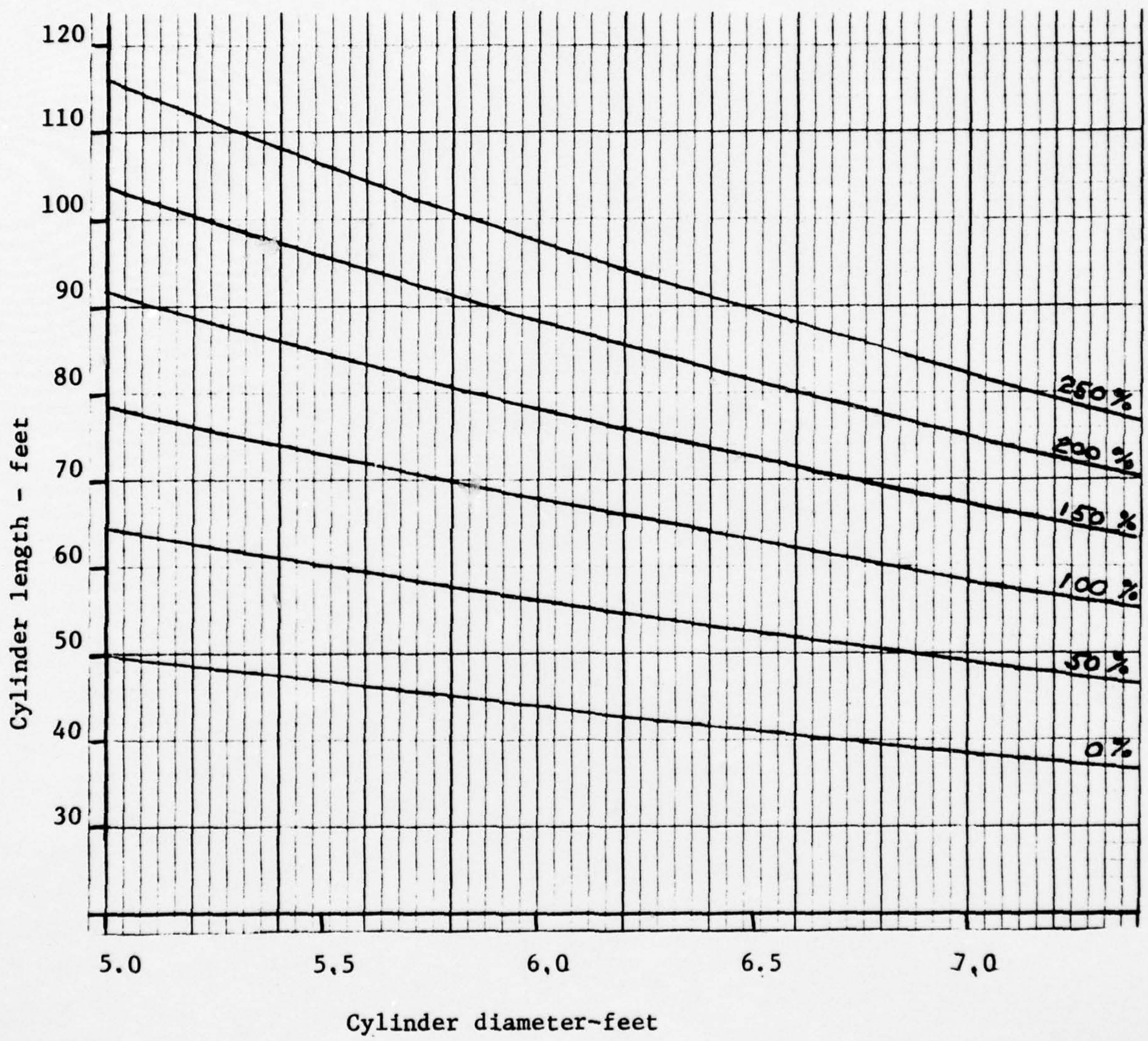

Figure B-26. Cylinder length chart for H/D = 2.0

MONOFORM

$\beta = 52^{o}$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

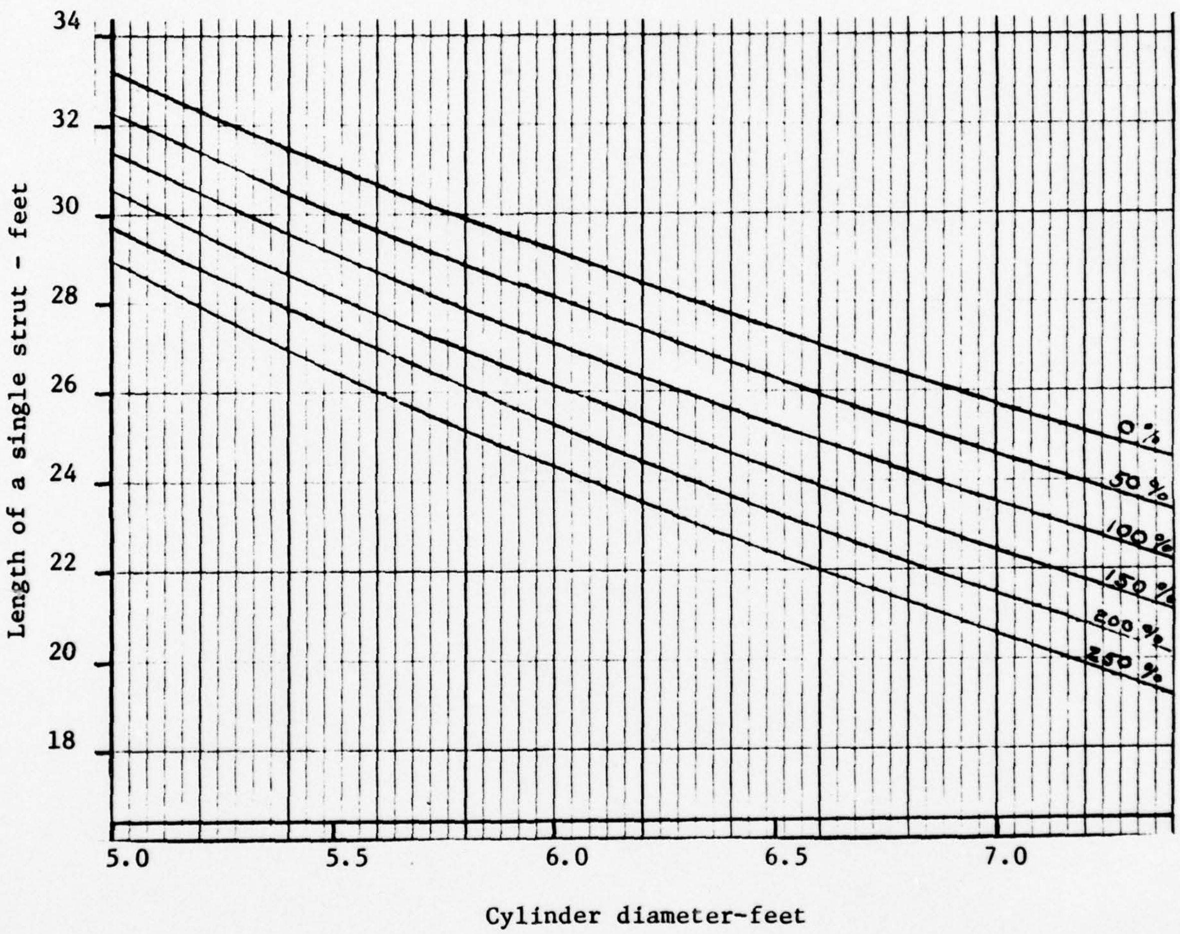

Figure B-27. Strut length chart for H/D = 2.0

MONOFORM

$\beta = 52^{o}$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

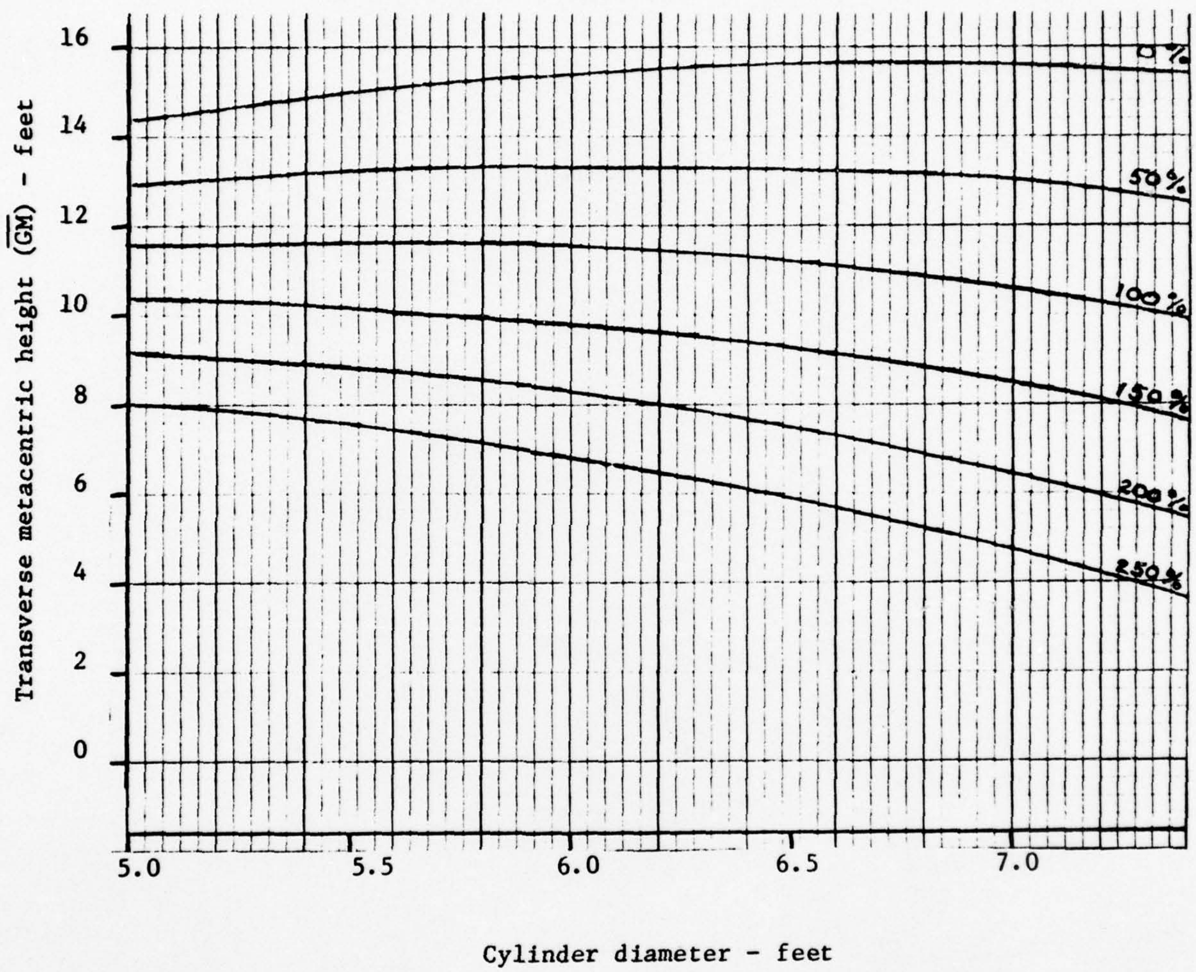

Figure B-28. Transverse metacenter chart for H/D = 2.0

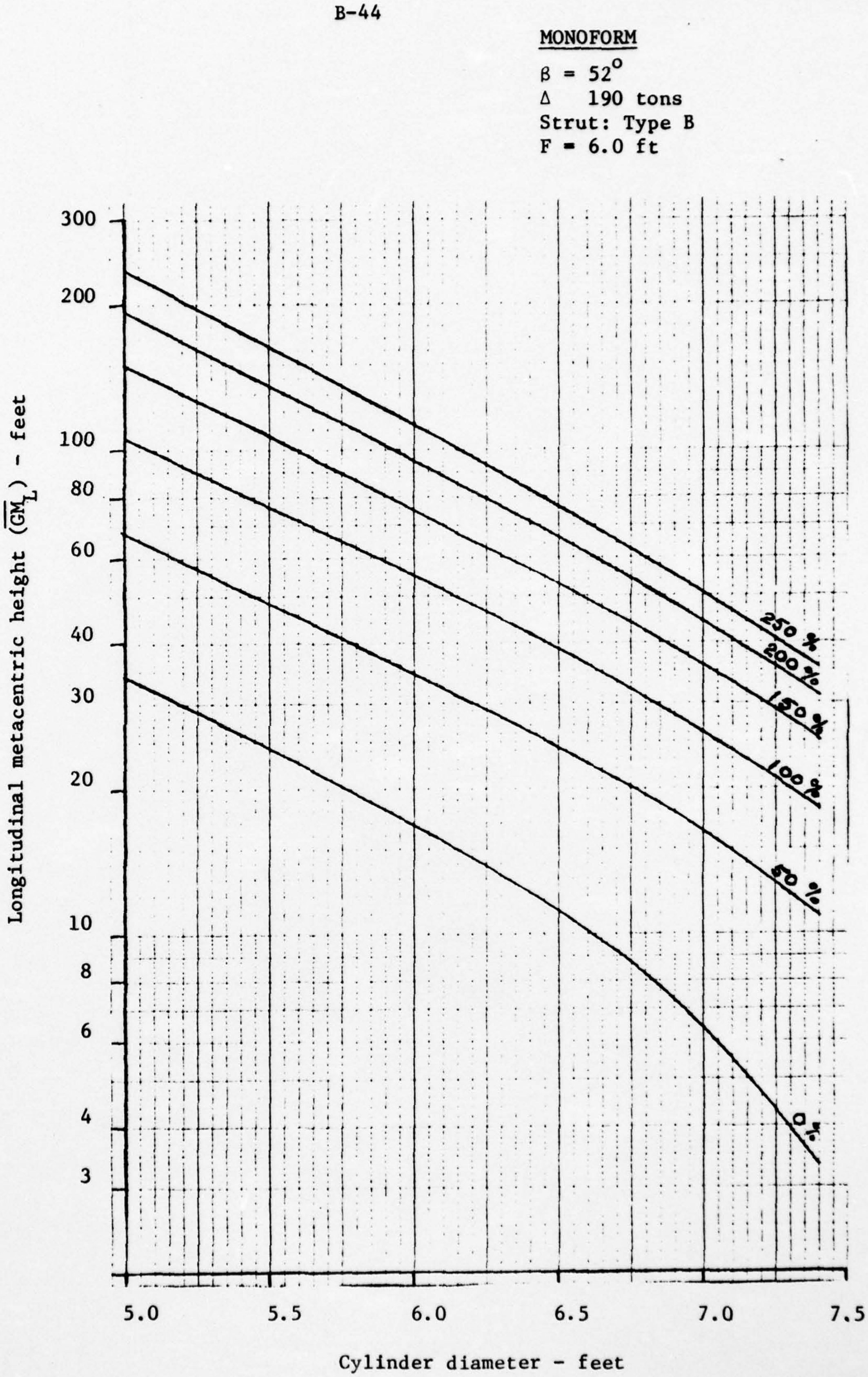

Figure B-29. Longitudinal metacenter chart for H/D = 2.0

MONOFORM

$\beta = 52^o$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

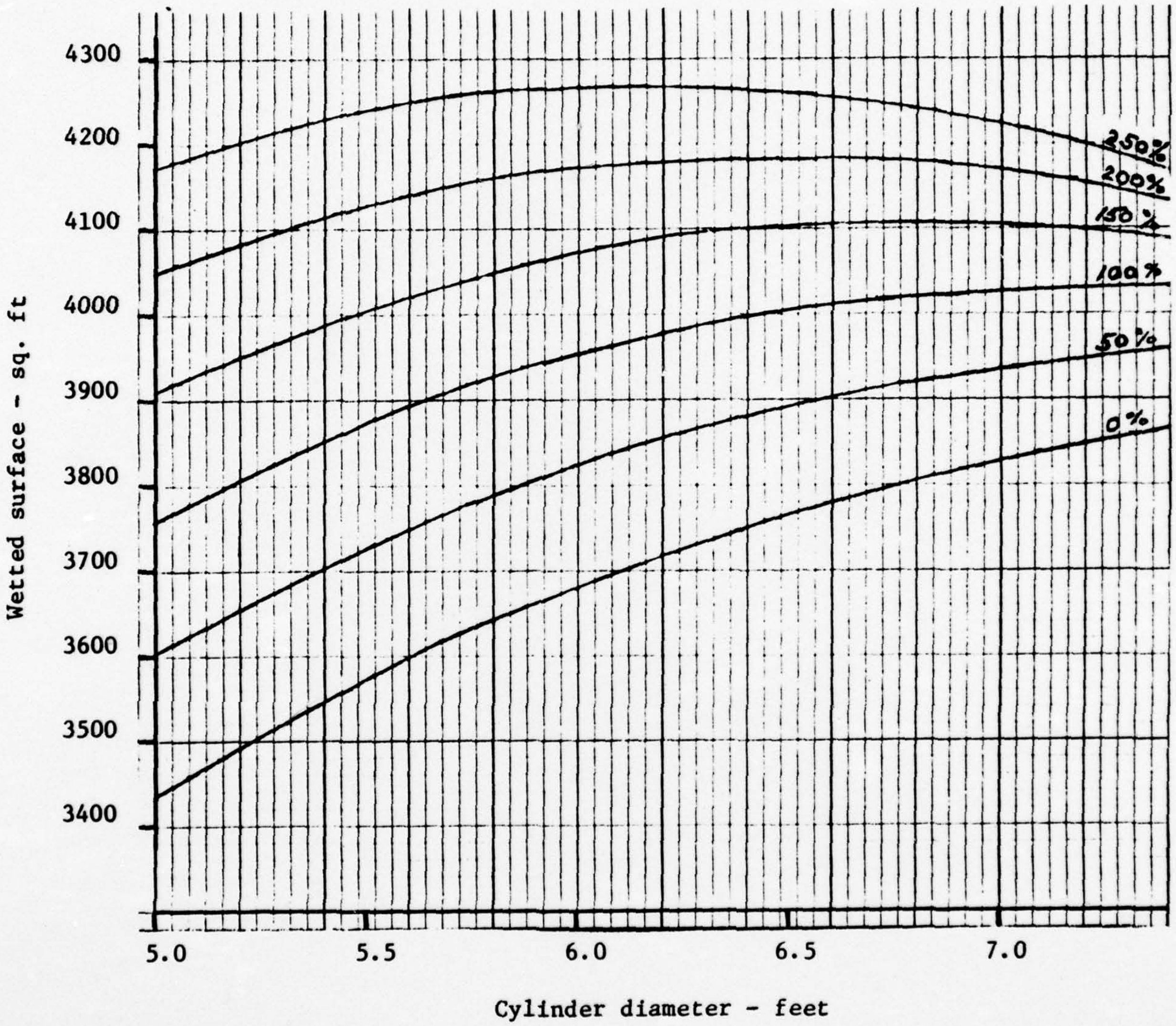

Figure B-30. Wetted surface chart for H/D = 2.0

MONOFORM

β = 52^{o}
Δ 190 tons
Strut: Type B
F = 6.0 ft

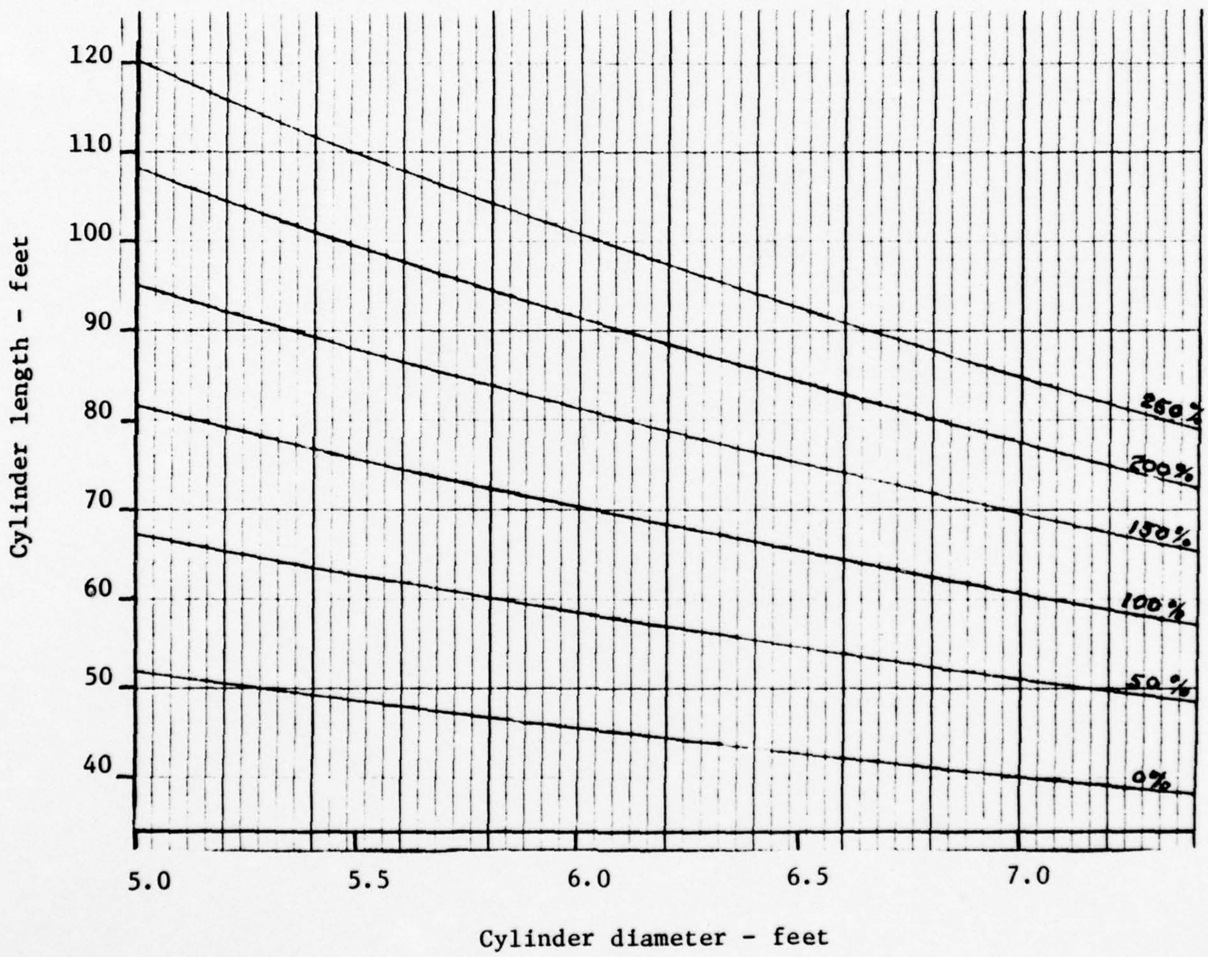

Figure B-31. Cylinder length chart for H/D = 1.85

MONOFORM

$\beta = 52^{\circ}$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

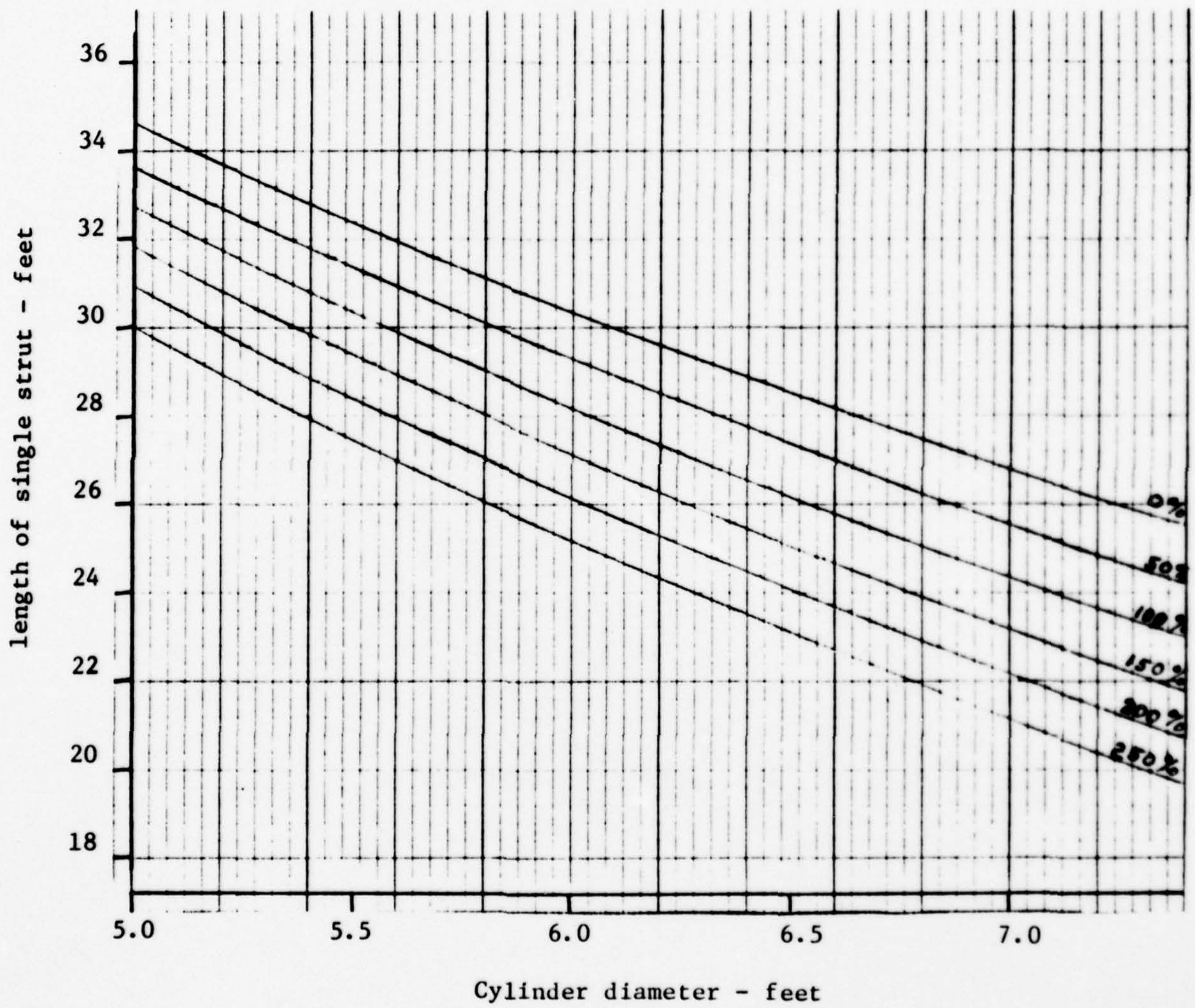

Figure B-32. Strut length chart for H/D = 1.85

MONOFORM

$\beta = 52^{o}$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

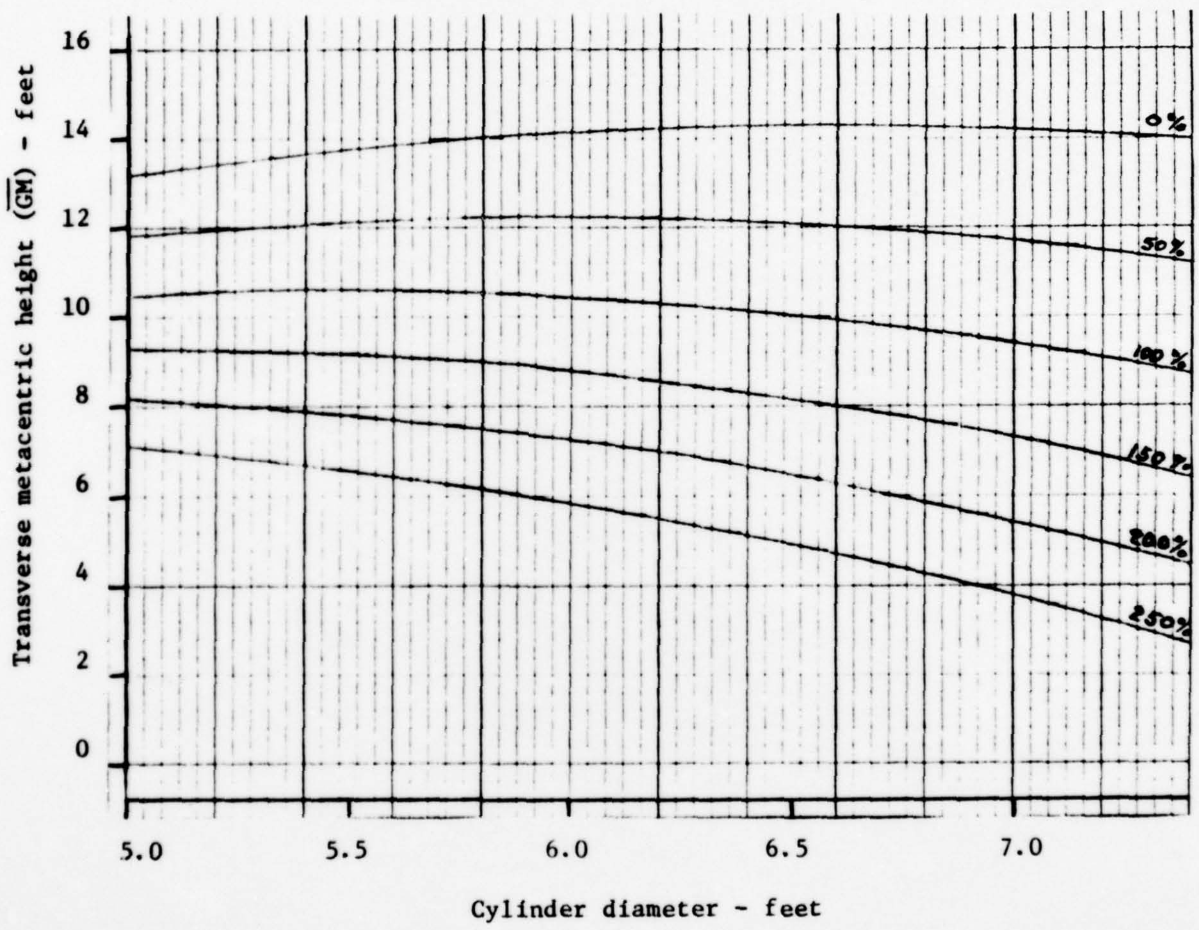

Figure B-33. Transverse metacenter chart for H/D = 1.85

MONOFORM

$\beta = 52^{o}$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

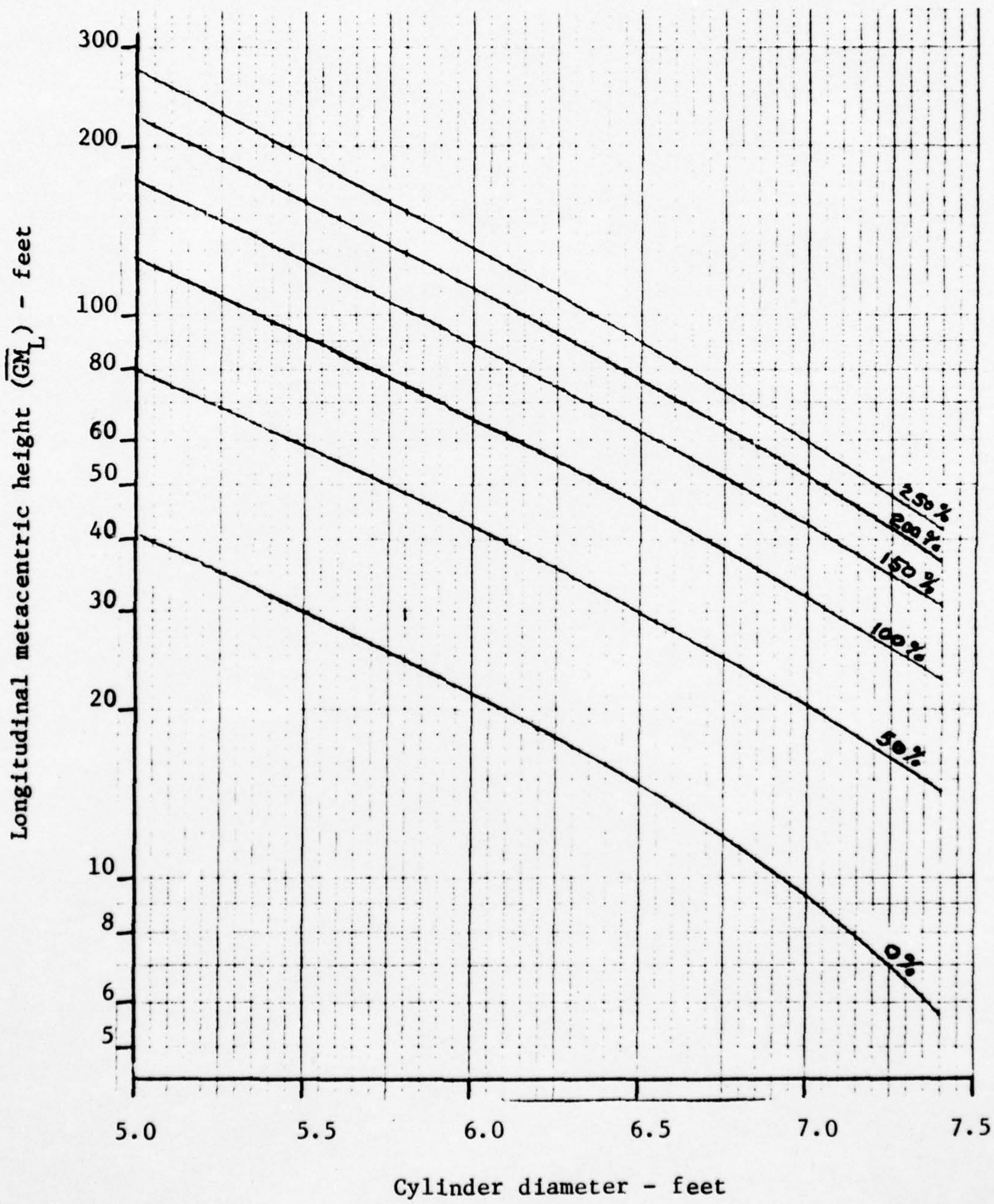

Figure B-34. Longitudinal metacenter chart for H/D = 1.85

MONOFORM

$\beta = 52^o$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

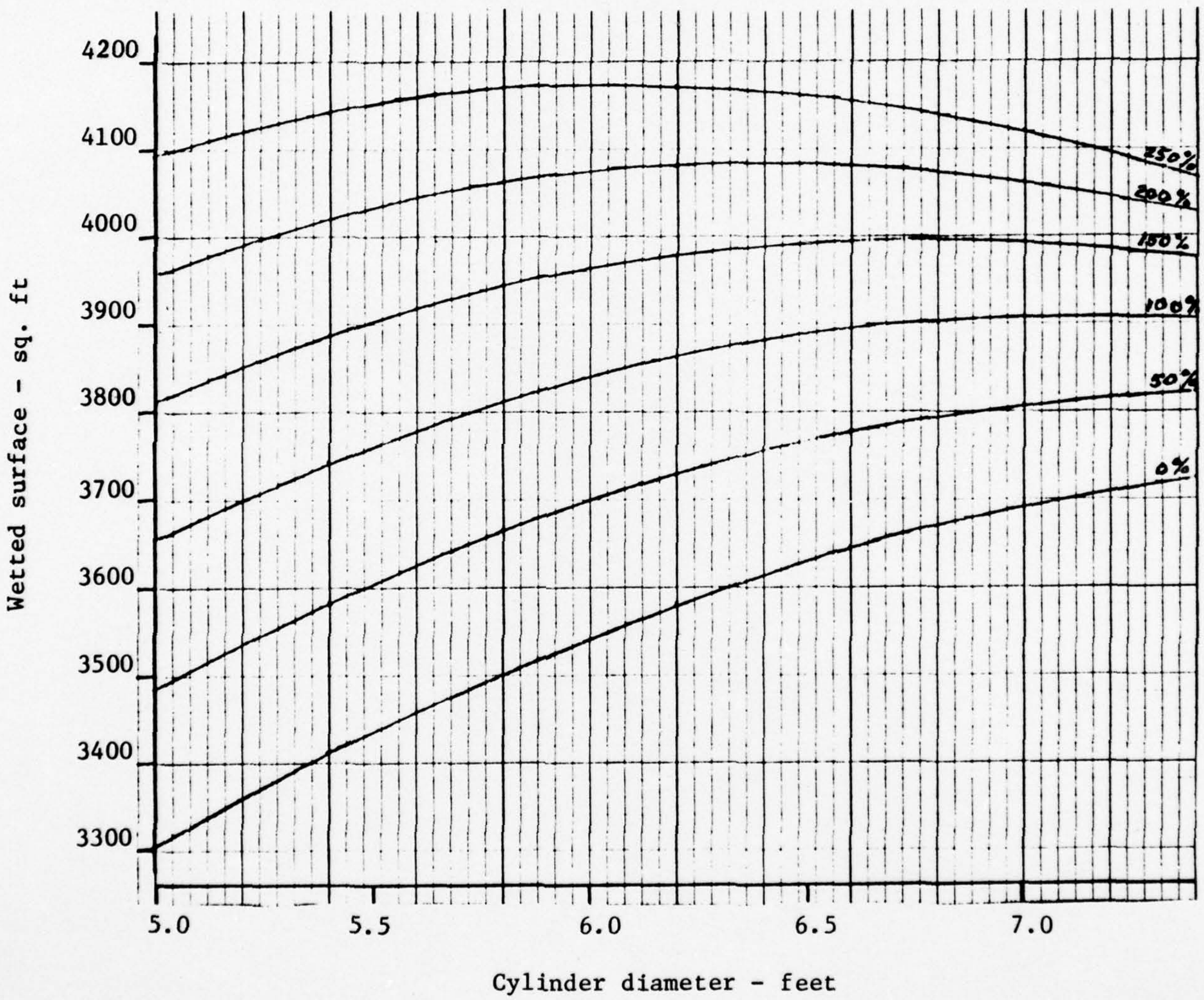

Figure B-35. Wetted surface chart for H/D = 1.85

MONOFORM

$\beta = 52^o$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

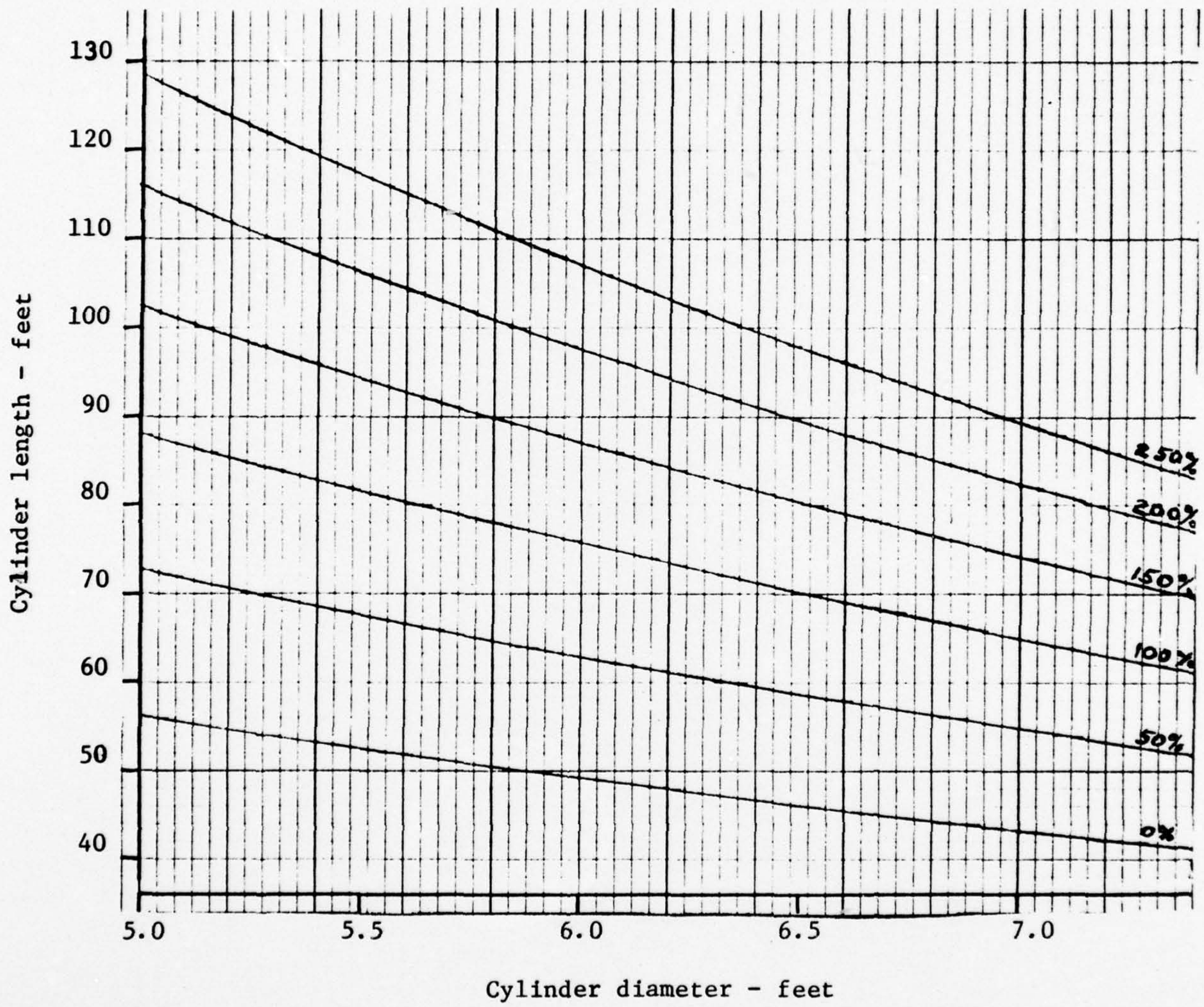

Figure B-36. Cylinder length chart for H/D = 1.6

MONOFORM

$\beta = 52^{o}$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

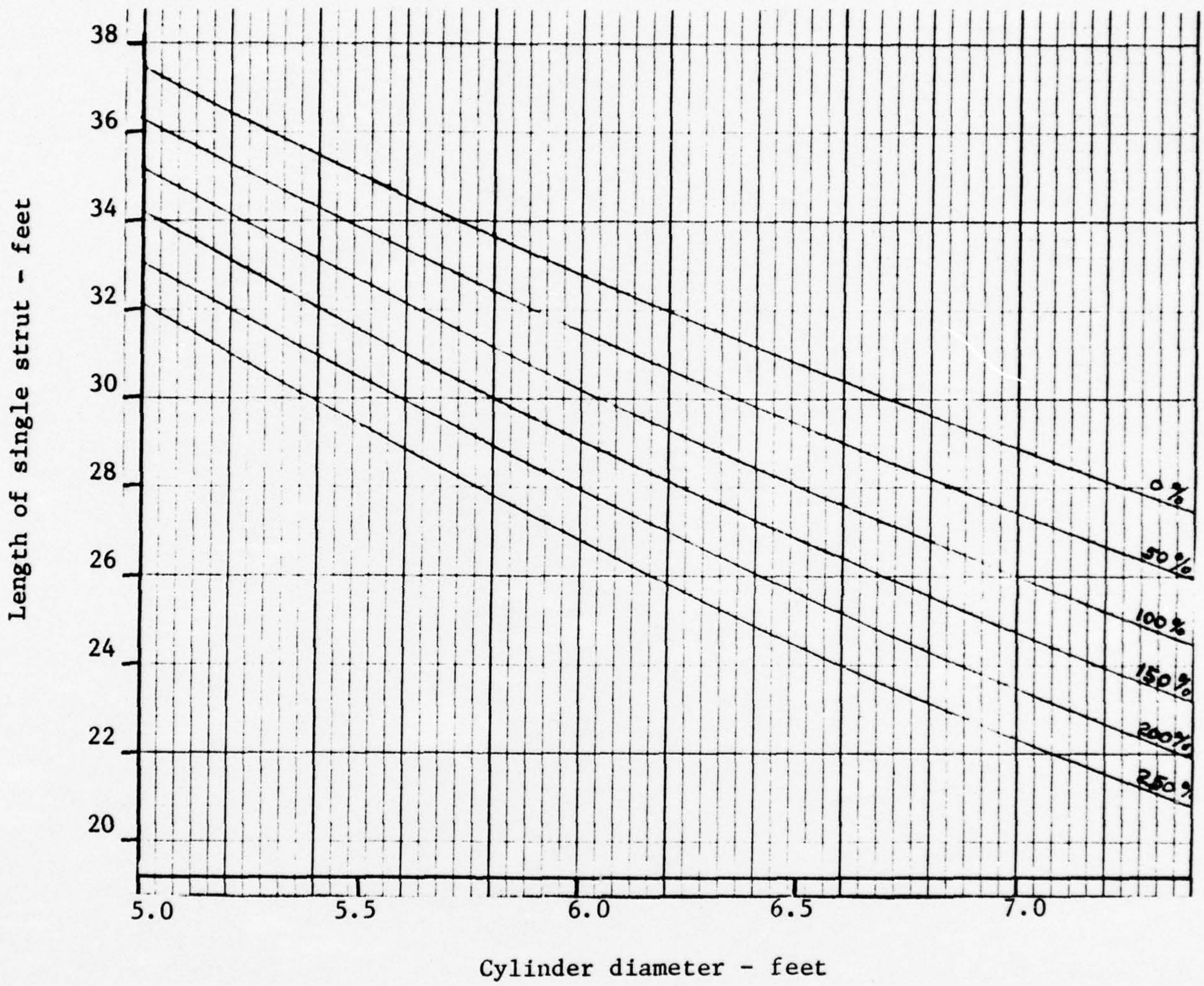

Figure B-37. Strut length chart for H/D = 1.6

MONOFORM

$\beta = 52^{\circ}$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

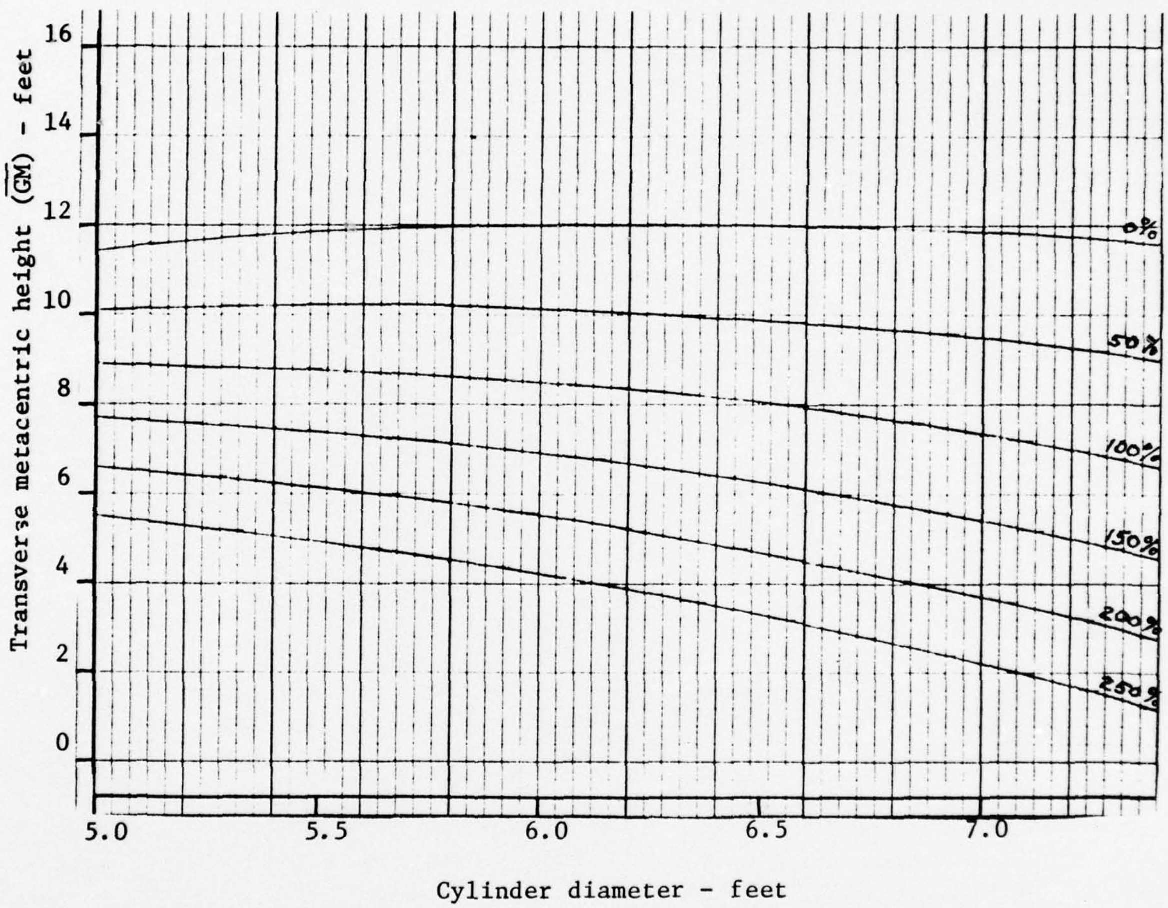

Figure B-38. Transverse metacenter chart for H/D = 1.6

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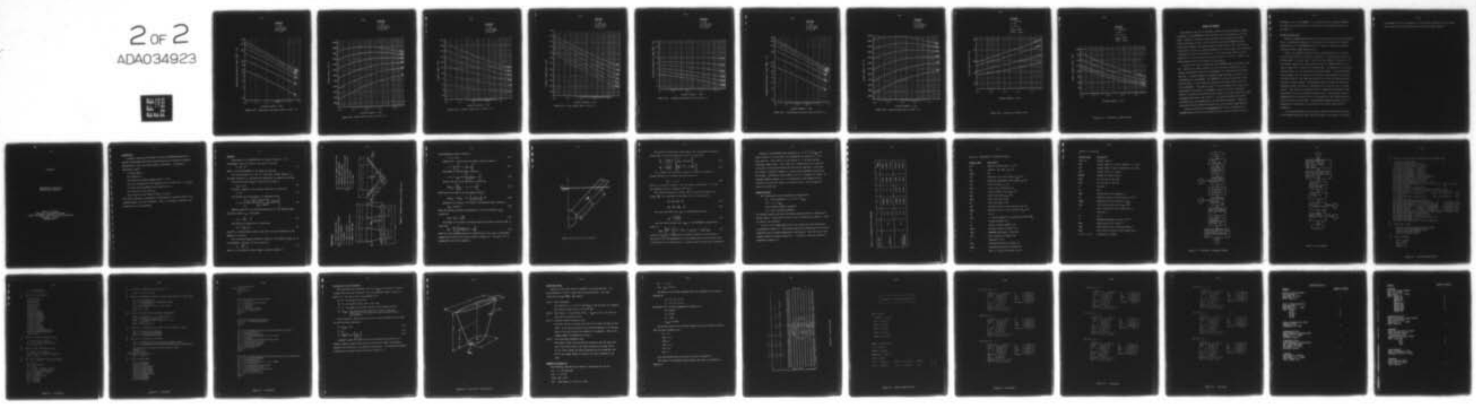

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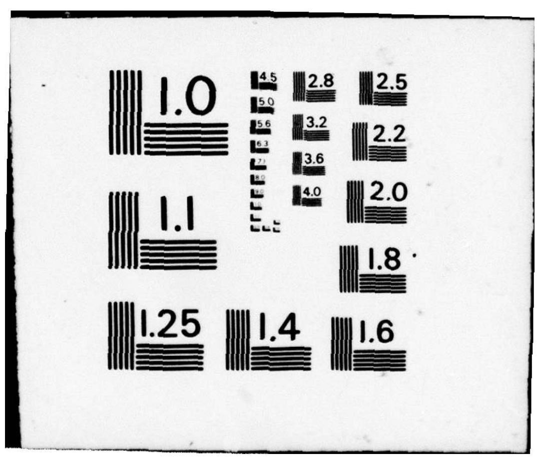
1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

MONOFORM

$\beta = 52^{o}$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

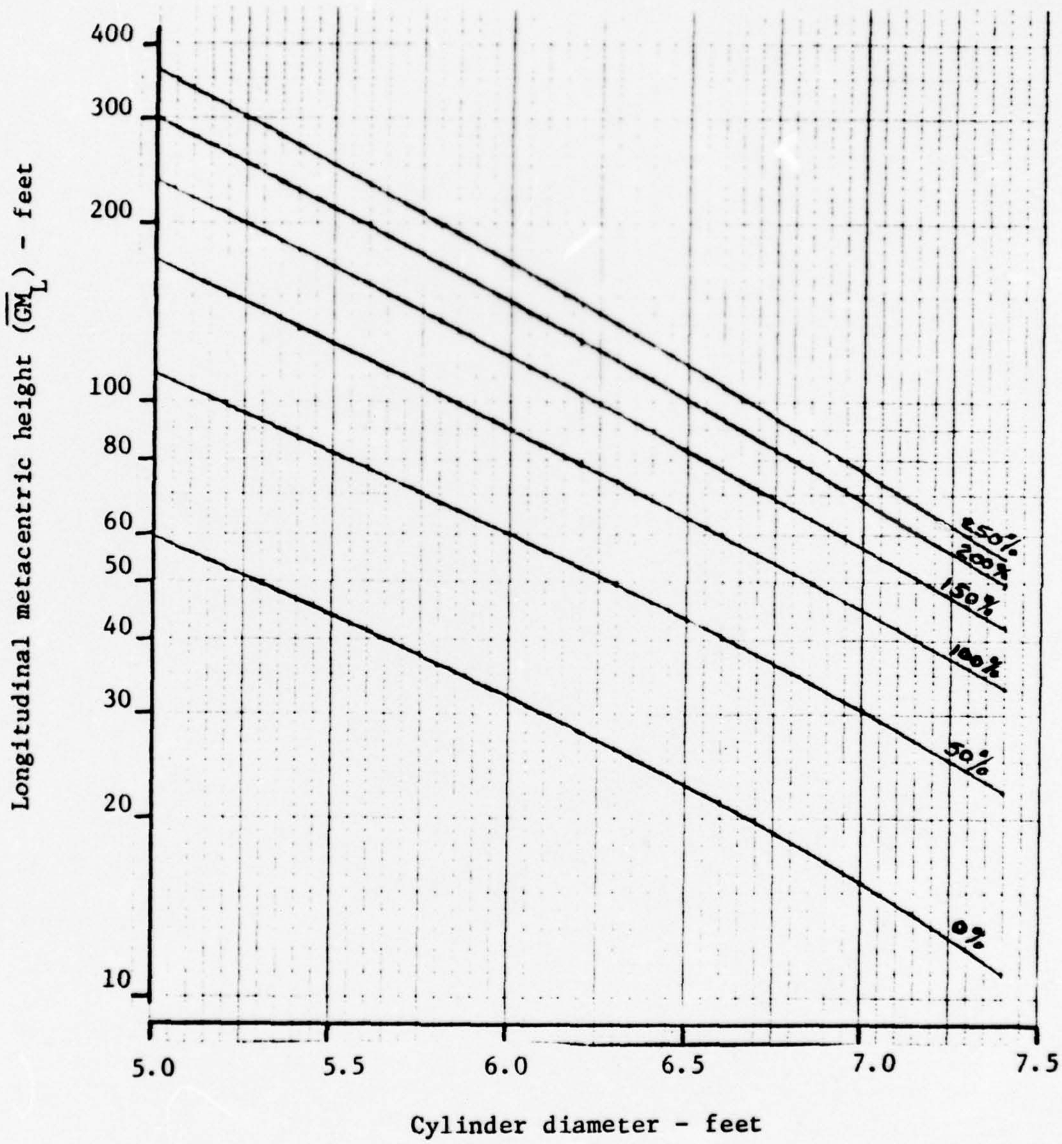

Figure B-39. Longitudinal metacenter chart for H/D = 1.6

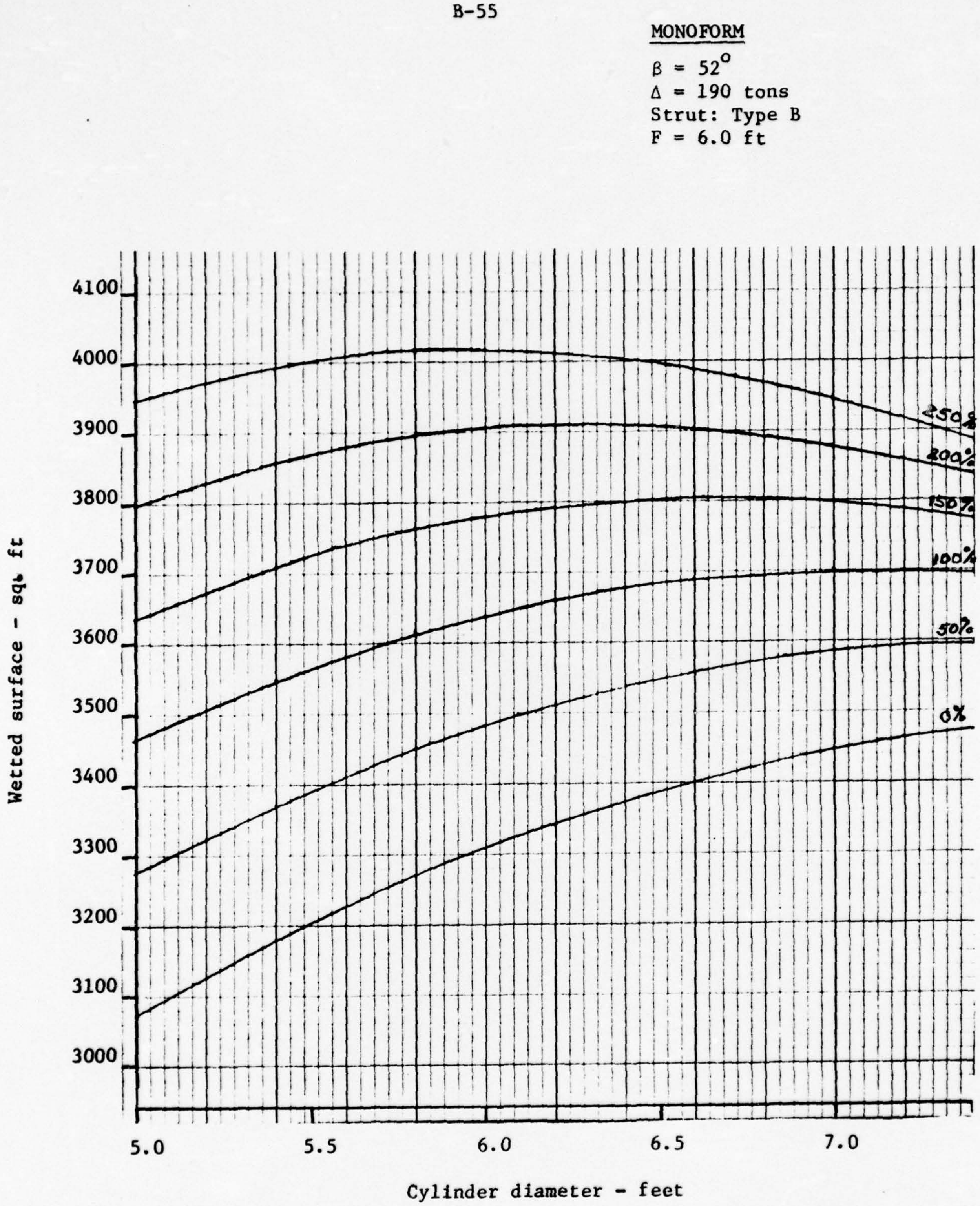

Figure B-40. Wetted surface chart for H/D = 1.6

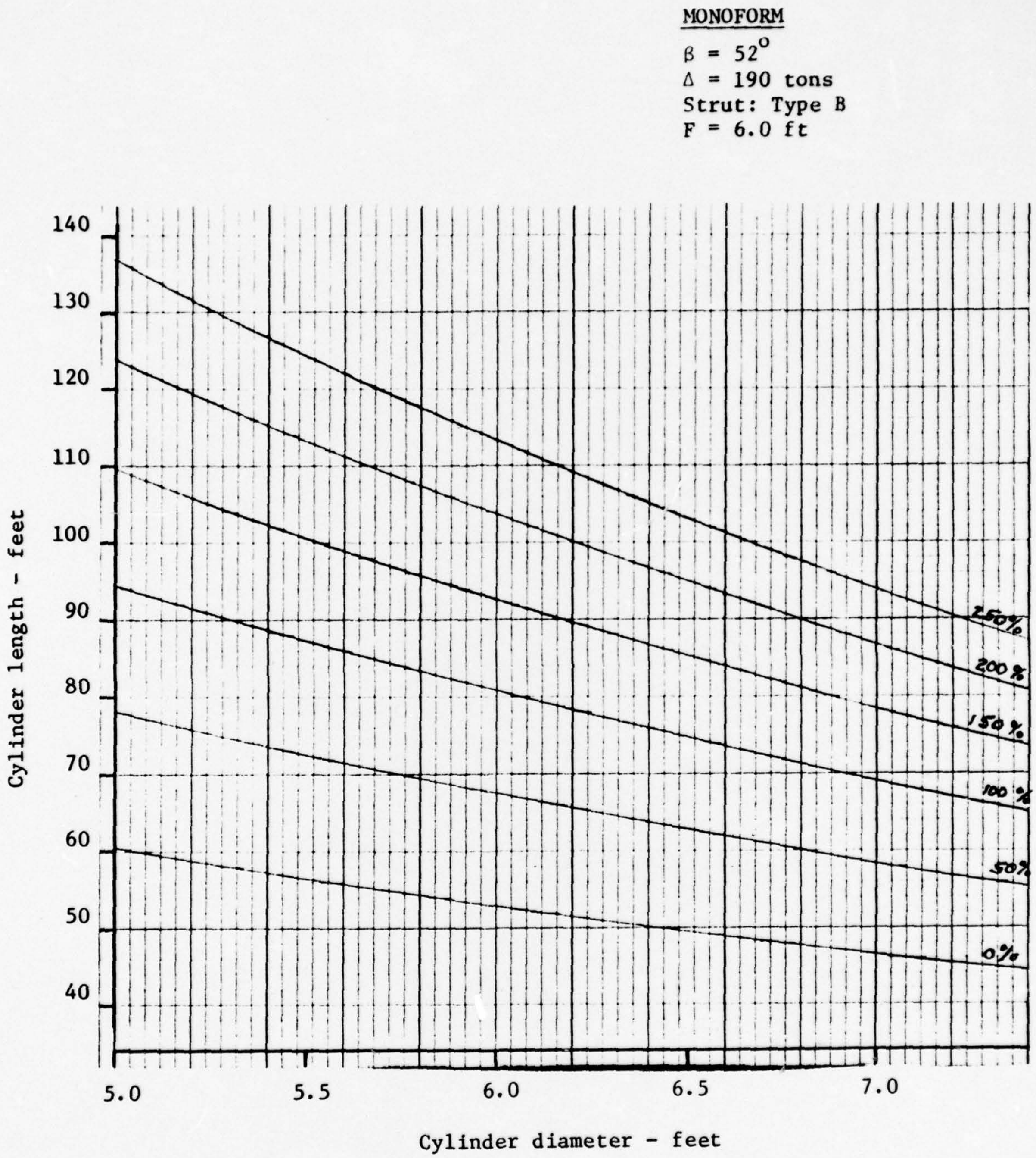

Figure B-41. Cylinder length chart for H/D = 1.4

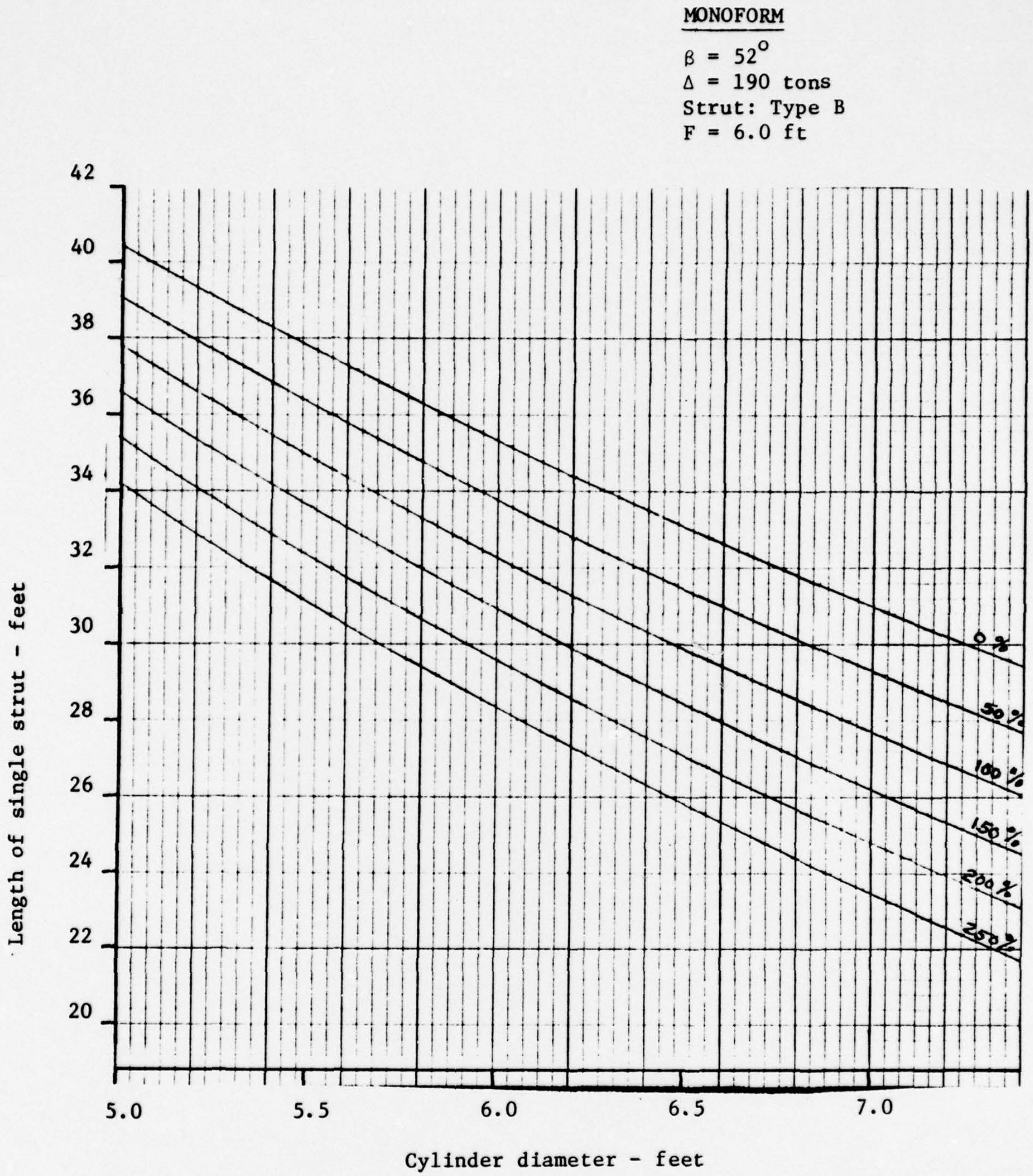

Figure B-42. Strut length chart for H/D = 1.4

MONOFORM

$\beta = 52^o$
Δ = 190 tons
Strut: Type B
F = 6.0 ft

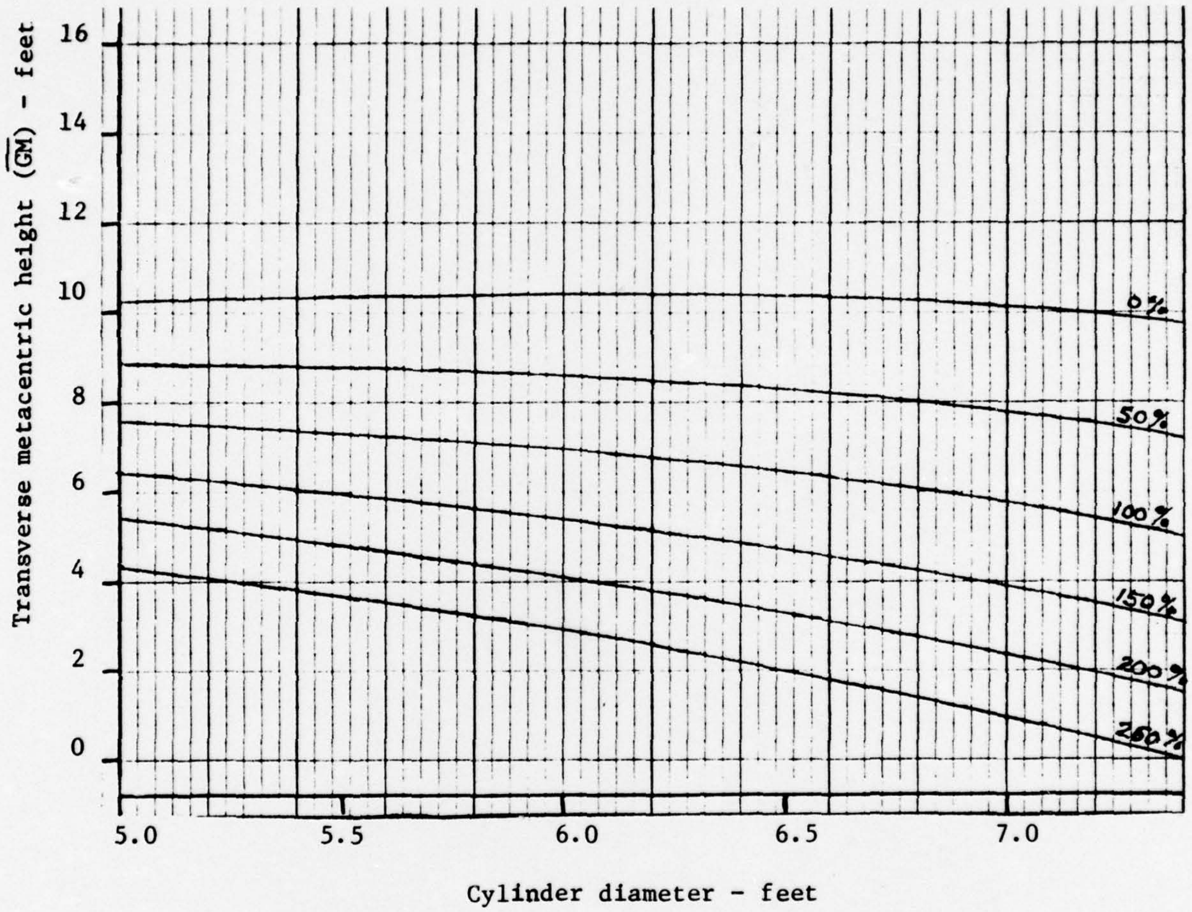

Figure B-43. Transverse metacenter chart for H/D = 1.4

MONOFORM

$\beta = 52^{o}$
$\Delta = 190$ tons
Strut: Type B
F = 6.0 ft

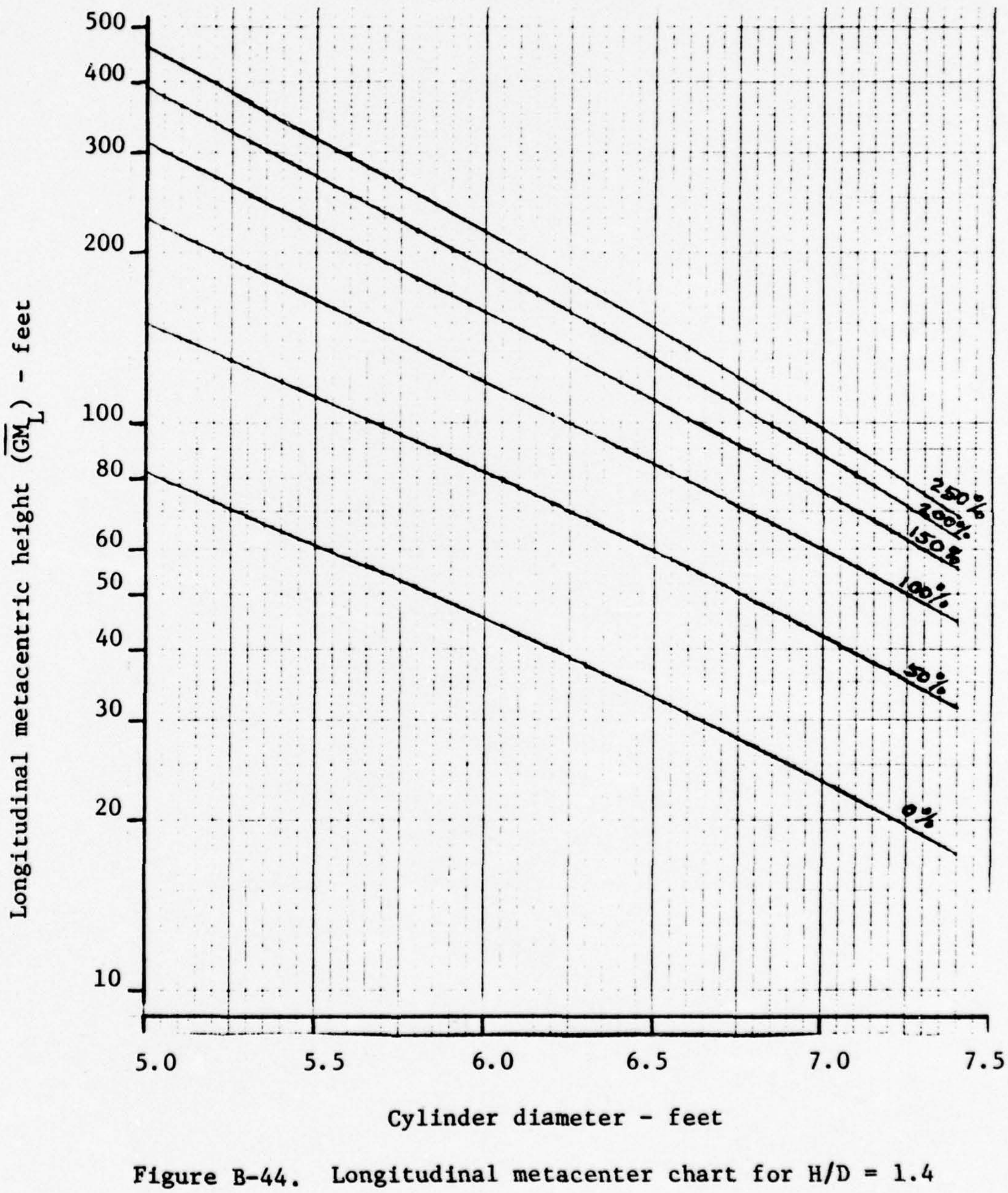

Figure B-44. Longitudinal metacenter chart for H/D = 1.4

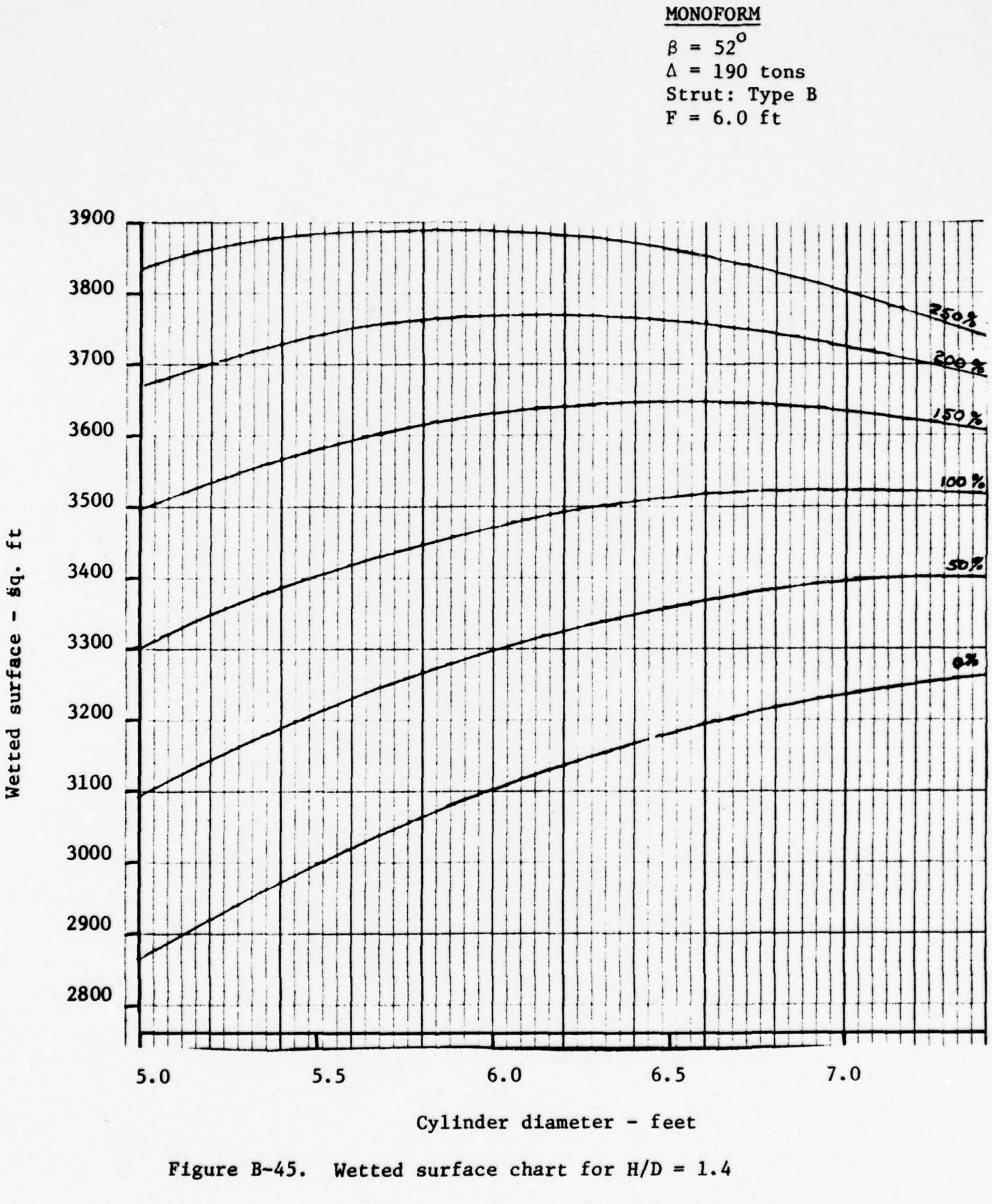

Figure B-45. Wetted surface chart for H/D = 1.4

MONOFORM

Δ = 190 tons

β = 52°

F = 6.0 ft

Gap_{WL} = 100%

Strut: Type B

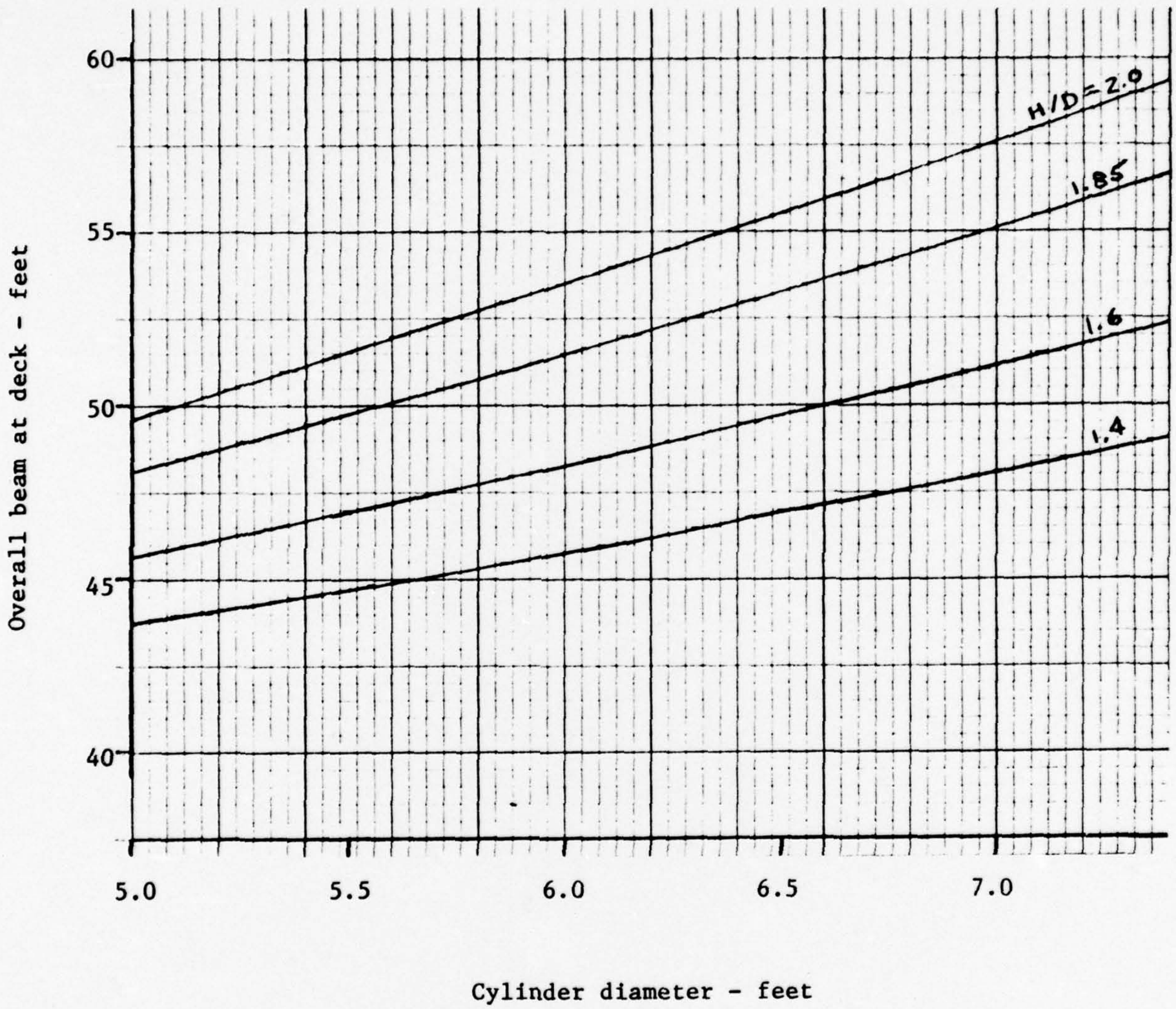

Figure B-46. Variations in beam at deck

MONOFORM

Δ = 190 tons

β = 52°

F = 6.0 ft

Gap_{WL} = 100%

Strut: Type B

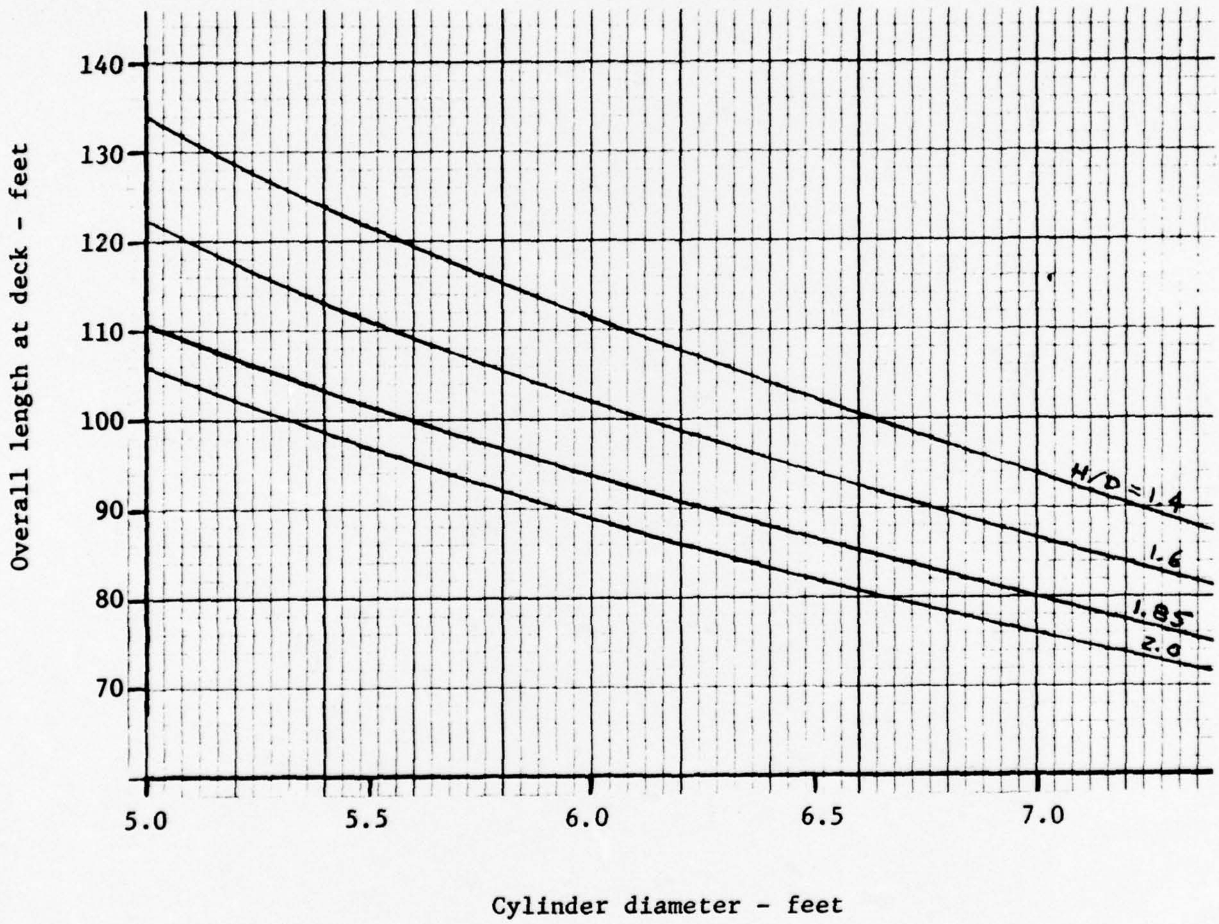

Figure B-47. Variations in length at deck

SUMMARY AND REMARKS

The results of two sets of parametric studies involving systematic changes in geometry of the MONOFORM hull were presented in the fore going part of this report. Because of the bulk of data generated, and the bulk of those which could be generated, only two, rather arbitrarily selected, MONOFORM configurations were compared with characteristics of NUC's 190-ton SSP. There was no attempt made to select an "optimum" MONOFORM hull, partly because what constitutes an optimum hull had not been defined yet. Such a definition would be rather subjective if it was not based on a specific mission of the ship. However, the mission analysis was not the subject of this project.

In most of the areas of comparison, both MONOFORM models scored better than SSP. Specifically, higher stability in both directions, reduced draft, and reduced wetted surface indicated the MONOFORM to be a more desirable platform than SSP. A slightly beamier and somewhat longer deck might or might not be an advantage for the MONOFORM. The MONOFORM's structure is basically closed while the SSP's is open, indicating simpler and therefore lighter structure for the MONOFORM. This might be upset by the extra weight of the larger deck. Between model A and model B of MONOFORM, the strut B version is decidedly superior in stability and wetted surface; however, the B type struts have larger waterplane areas than A type struts do. The larger waterplane areas might adversely affect sea keeping quality and wavemaking resistance. These two areas must be further explored theoretically, and preferably experimentally.

It must be pointed out and <u>emphasized</u> again that no optimization of MONOFORM characteristics was attempted and that structural analysis was not

performed at all on the MONOFORM. It is possible that an "optimum" MONOFORM hull might out-perform the SSP even more than the two examples discussed in the report do.

Outline of Future Work

During the remaining three months of the project two tasks will be performed. First, a hydrodynamic analysis will be carried out to estimate the resistance characteristics of the MONOFORM hull and, if possible, establish an optimum separation distance (gap) between struts.

Second, the parametric analysis will be continued partly in the present form to include smaller strut angles, and partly in a new direction, which will be named model C, or strut type C. This strut will produce, in addition to its own buoyancy, dynamic lift either because of having a cambered profile or because of deflection of flaps at the trailing edge. The dynamic lift will reduce the draft which, in turn, will reduce the wetted surface. If the lift-induced drag is smaller than the reduction in the viscous drag (because of a decrease in wetted surface), a net drag reduction will occur with an accompanying power reduction or speed increase. The decreased draft will reduce the transverse metacentric height (and also the longitudinal one in case of strut B configuration). This reduction in stability will be countered by the dynamic stabilizing effect of the lift producing V-shaped struts. (This dynamic stability augmentation will be present but not as pronouncedly in the symetric-profiled strut A and strut B cases also). The dynamically augmented stability will be beneficial for the mission of the platform, for example, during aircraft operations.

It is sincerely hoped, that the results already obtained and the results to be obtained during the third (and final) phase of the project will warrant

the extension of this investigation to include model experiments in the towing tank, as well as relatively detailed structural and weight analyses.

APPENDIX C

COMPUTERIZED SELECTION OF MONOFORM HULL DIMENSIONS

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Introduction

A computer program was developed for selecting MONOFORM geometries of specific displacement which would provide satisfactory hydrostatic stability characteristics while satisfying geometric constraints. The geometric constraints include:

(i) displacement, Δ

(ii) freeboard, F,

(iii) draft-to-cylinder diameter ratio, $\alpha = H/D$,

(iv) strut thickness-to-chord length ratio at the waterline, $t = T_s/L_{SWL}$,

(v) strut base-to-waterline chord length ratio, ξ,

(vi) beam at the deck edge, B_{DE}

(vii) location of the vessel's center of gravity

With these constraints, the geometry is determined for selected values of the cylinder diameter and strut thickness. Thus, the hydrostatic stability characteristics are also determined.

Analysis

The geometry of the MONOFORM hull is shown in Figure C-1. The displacement volume of a ship in salt water is given by

$$\forall = 35\Delta \quad ft^3 \tag{1}$$

where Δ is the displacement of the vessel in long tons.

For the constraints i-vii and for a specified cylinder diameter, D, and strut thickness, T_s, the other hull dimensions are computed as follows:

The waterline chord length of each strut is given by

$$L_{SWL} = T_s/t \tag{2}$$

The draft, measured to the cylinder centerline, is found from

$$H = \alpha D \tag{3}$$

The required strut half-angle, β, is determined from

$$\beta = \sin^{-1}\left[\frac{B_{DE}\sqrt{B_{DE}^2 + 4(H+F)^2 - T_s^2} - 2T_s(H+F)}{B_{DE}^2 + 4(H+F)^2}\right] \tag{4}$$

Employing Equation 4, the following expression for the submerged span-wise strut length, L_{ss}, is obtained.

$$L_{ss} = \frac{H}{\cos\beta} - \frac{D}{2} \tag{5}$$

The volume of a single strut is found from

$$\forall_s = \overline{\forall}\, L_{SWL}^2\, L_{ss} \tag{6}$$

where $\overline{\forall}$ is a dimensionless constant whose value is solely dependent on the geometry of the strut.

For a conically-shaped afterbody of length 2D, the combined volume, $\forall_c$, of the hemisphere, cylinder, and cone is given by

$$\forall_c = \frac{\pi D^2}{4} L_c \tag{7}$$

where L_c is the nominal cylinder length as shown in Figure C-1.

NOMENCLATURE:

B = overall beam at deck

B_{WL} = beam at waterline (nominal)

D = cylinder diameter

F = freeboard

G = center of gravity

H = draft to cylinder centerline

L = length at deck edge

L_B = strut chord length at strut base

L_C = cylinder length (nominal)

L_S = span-wise strut length

L_{SS} = submerged span-wise strut length

L_{SWL} = strut chord length at waterline

T_s = strut thickness

β = strut angle

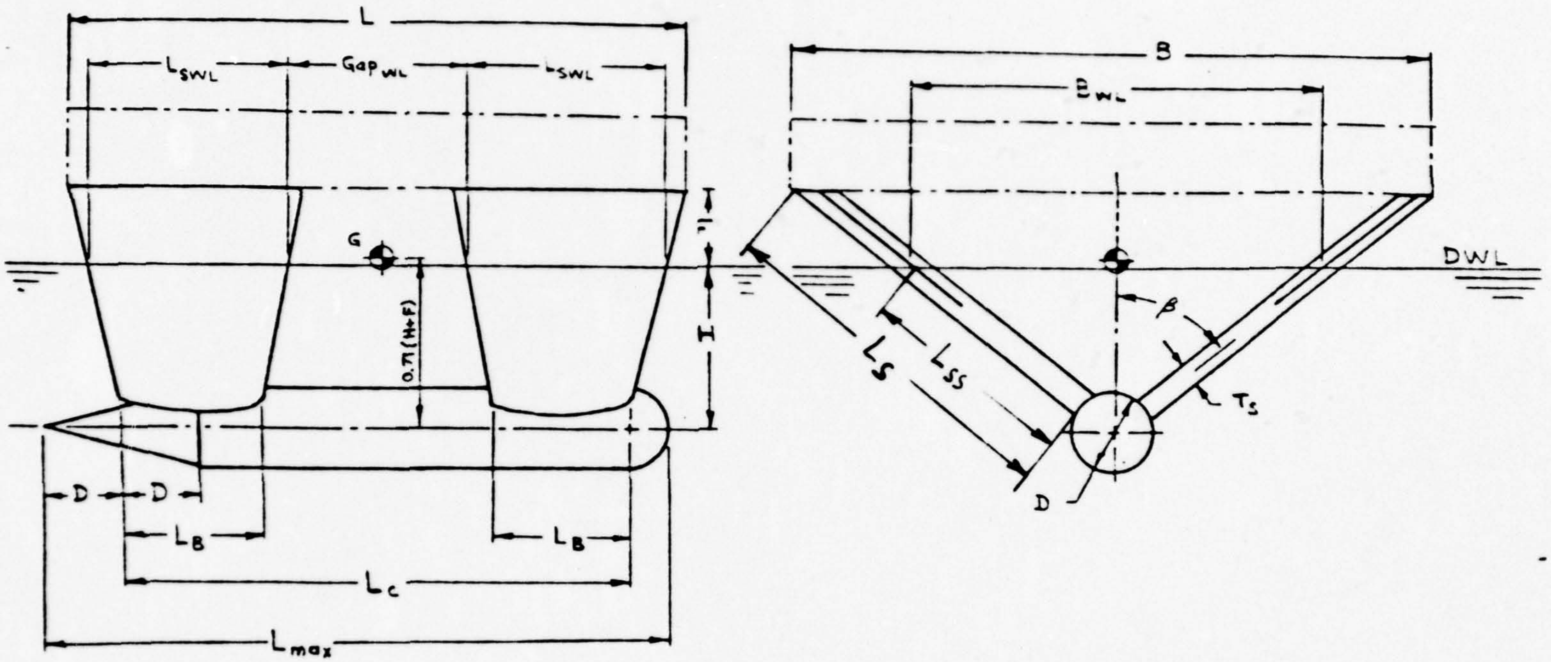

Figure C-1 Monoform Geometry and Nomenclature

The displacement volume is given by

$$\forall = \forall_c + 4\forall_s \tag{8}$$

Equations 6, 7, and 8 yield the nominal cylinder length as

$$L_c = \frac{4}{\pi D^2}\left[\forall - 4\, L_{SWL}^2\, L_{ss}\right] \tag{9}$$

The length at the deck edge is given by

$$L = L_c + L_{SWL}\ (1-\xi)\left[\frac{F}{L_{ss}\cos\beta} + 1\right] \tag{10}$$

The per cent gap at the waterline is found from

$$\%GAP_{WL} = \left[\frac{L_c}{L_{SWL}} - (1+\xi)\ 100\right] \tag{11}$$

while the per cent gap at the deck edge is given by

$$\%GAP_{DE} = \%GAP_{WL} - (1-\xi)\left[\frac{F}{L_{ss}\cos\beta}\right] 100 \tag{12}$$

Measured to the center of the sturts, the waterline beam is given by

$$B_{WL} = 2H\tan\beta, \tag{13}$$

while the extreme waterline beam measured to the strut outbouard, B_{WLE}, is given by

$$B_{WLE} = B_{WL} + \frac{T_s}{\cos\beta} \tag{14}$$

The height of the center of buoyancy above the cylinder centerline, $\overline{RB}$, is found from

$$\overline{RB} = \frac{4\forall_s}{\forall}\left[\frac{D(1-\overline{Y})\cos\beta}{2} + H\overline{Y}\right] \tag{15}$$

where $\overline{Y}$ is the normalized distance of the centroid of the strut's displacement volume from the base of the strut as shown in Figure C-2. The value of $\overline{Y}$ is determined by the strut's geometry.

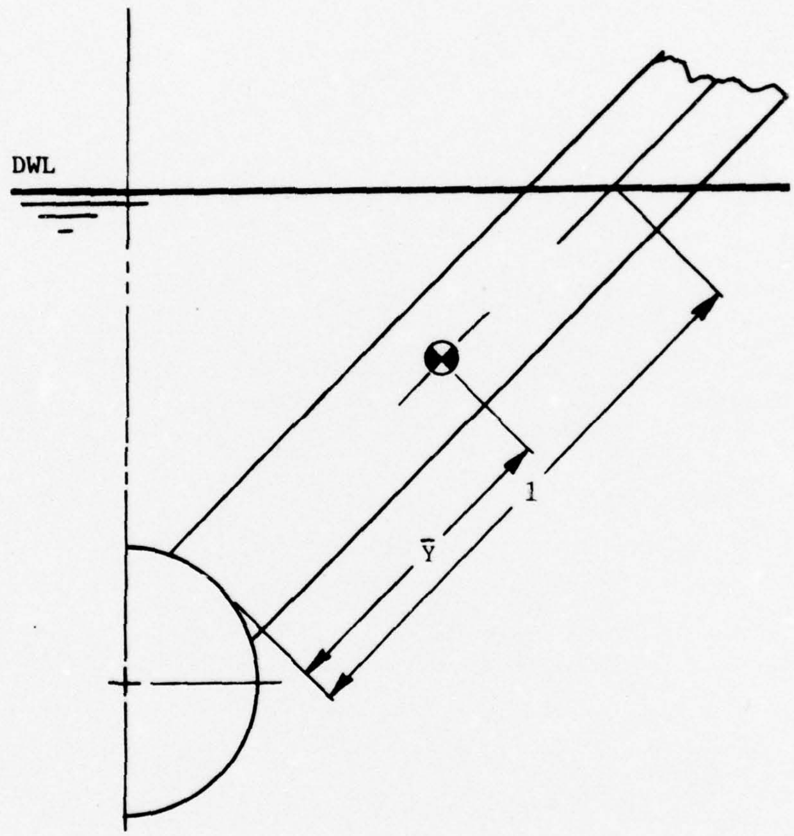

Figure C-2 Location of Strut Centroid

The transverse metacentric radius, $\overline{BM}$ and the longitudinal metacentric radius, $\overline{BM}_L$, are given by Equations 16 and 17, respectively

$$\overline{BM}_L = \frac{4\ L_{SWL}\ T_s}{3\ \cos^3\ \beta} \left[\frac{T_s^{\ 2}}{8.75} + 2H^2 \sin^2 \beta \right] \quad (16)$$

$$\overline{BM}_L = \frac{4\ L_{SWL} T_s}{3\ \cos\ \beta} \left[\frac{L_{SWL}^{\ 2}}{10} + \frac{(L_L - \xi\ L_{SWL})^2}{2} \right] \quad (17)$$

It is assumed that the vessel's center of gravity is located at a distance $\overline{RG}$ above the cylinder centerline such that

$$\overline{RG} = \kappa\ (F + H) \quad (18)$$

where κ is a selected constant. (For the sample calculations $\kappa = 0.71$ has been employed, based on comparative SSP data.)

The transverse metacentric height, $\overline{GM}$, and longitudinal metacentric height, $\overline{GM}_L$, are determined by Equations 19 and 20, respectively.

$$\overline{GM} = \overline{RB} + \overline{BM} - \overline{RG} \quad (19)$$

$$\overline{GM}_L = \overline{RB} + \overline{BM}_L - \overline{RG} \quad (20)$$

The total waterplane area, A_{WP}, is approximately given by

$$A_{WP} = \frac{8\ T_S L_{SWL}}{3\ \cos\ \beta} \quad (21)$$

The total wetted surface area, S_{WET}, of the MONOFORM is approximately given by

$$S_{WET} \simeq \left[\frac{\sqrt{17}}{4} - \frac{1}{2} \right] \pi D^2 + \pi D L_C + 4\ L_{SWL} L_{SS} \overline{S} - 4\ L_{SWL}^{\ 2}\ \overline{S}_{CORR} \quad (22)$$

where $\overline{S}$ and $\overline{S}_{CORR}$ are dimensionless constants dependent on strut geometry, The value of $\overline{S}$ is an approximation to the dimensionless, lateral surface area of the strut and its value varies to a slight degree with the struts dimensions.

Values of the normalized strut parameters (t, ξ, $\overline{V}$, $\overline{Y}$, $\overline{S}$, $\overline{S}_{CORR}$) are found in Table C-1 for two basic strut geometries for values of $t = 0.13$, 0.15, and 0.17. Strut Type A is a non-tapered ($\xi = 1.0$) strut having a lenticular cross-section. Strut Type B is a tapered strut ($\xi = 0.50$) with a lenticular cross-section between the deck and the 20% draft of the strut. From there, it gradually changes to a blunt-nosed streamlined cross-section at the base. Although the chord-length of the strut changes with height, its thickness remains constant, i.e., the thickness to chord-length ratio is smallest at the deck and largest at the base; while it has the specified value at the waterline.

Computer Program

The following data must be supplied as program input:

(i) Strut parameters; t, ξ, $\overline{V}$, $\overline{Y}$, $\overline{S}$, $\overline{S}_{CORR}$

(ii) Δ, F, κ B_{DE}, α

(iii) Cylinder diameter parameters

(iv) Strut thickness parameters

The cylinder diameter and strut thickness parameters provide a combinatorial solution matrix. They provide initial values, increments, and number of values for each of the variables.

A list of the variable names used in the program and their description is presented in Table C-2. The variable names were selected such as to provide similarity with the symbols appearing in the analysis. The flow chart of the computer program is shown in Figure C-3. A listing of the source program is presented in Figure C-4.

Table C-1. Normalized Strut Parameters

Strut Type	ξ	t	$\overline{V}$	$\overline{Y}$	$\overline{S}$	$\overline{S}_{CORR}$
A (Lenticular)	1.0	0.13	0.08667	0.5	2.0225	0.08667
		0.15	0.10000	0.5	2.0299	0.10000
		0.17	0.11333	0.5	2.0382	0.11333
B (Lenticular/ Streamlined)	0.5	0.13	0.06918	0.5536	1.5399	0.04719
		0.15	0.07991	0.5534	1.5524	0.05445
		0.17	0.09070	0.5533	1.5662	0.06171

Table C-2. Description of Program Variables

Variable Name	Description
ALC	Nominal cylinder length, L_C (ft)
ALD	Length at deck edge, L_{DE} (ft)
ALPHA	H/D
ALS	Waterline strut chord length, L_{SWL} (ft)
ALSS	Submerged (span-wise) strut length L_{SS} (ft)
ATS	Strut thickness, T_S (ft)
ATS1	Initial strut thickness (ft)
AWP	Total waterplane area, A_{WP} (ft^2)
BDE	Beam at deck edge, B_{DE} (ft)
BETA	Strut half-angle (deg)
BR	Strut half-angle (rad)
BWL	Waterline beam (to strut centers), B_{WL} (ft)
BWLE	Waterline beam (to strut outboard), B_{WLE} (ft)
CB	cos β
CON	κ, constant employed in calculation of $\overline{GM}$ and $\overline{GM}_L$
D	Cylinder diameter (ft)
D1	Initial cylinder diameter (ft)
DDIA	Cylinder diameter increment (ft)
DISP	MONOFORM displacement (long tons)
DTS	Strut thickness increment (ft)
F	Freeboard, F (ft)
GMT	Transverse metacentric height (ft)
GMLA	Longitudinal metacentric height (ft)
H	Draft to cylinder centerline, H (ft)

Table C-2. (continued)

Variable Name	Description
IDIA, ITS	Integer counters
KDIA	Integer number of cylinder diameters to be used
KTS	Integer number of strut thicknesses to be used
KSOL	Integer counter for output
MKOUNT	Integer for output spacing
PGDE	Per cent gap at deck edge
PGWL	Per cent gap at waterline
PI	Constant, π
SB	sin β
SBAR	Dimensionless strut parameter, $\overline{S}$
SC	Combined cylinder wetted surface area (ft^2)
SCORR	Dimensionless strut parameter, $\overline{S}_{CORR}$
STOT	Total wetted surface area, S_{WET} (ft^2)
T	Strut thickness-to-chord length ratio at waterline, t
TB	tan β
V	MONOFORM displacement volume, $\forall$ (ft^3)
VBAR	Dimensionless strut volume, $\overline{V}$
YBAR	Dimensionless strut centroidal height, $\overline{Y}$
ZETA	Strut base-to-waterline chord length ratio, ξ
A1, B1, C1, etc.	Intermediate variables

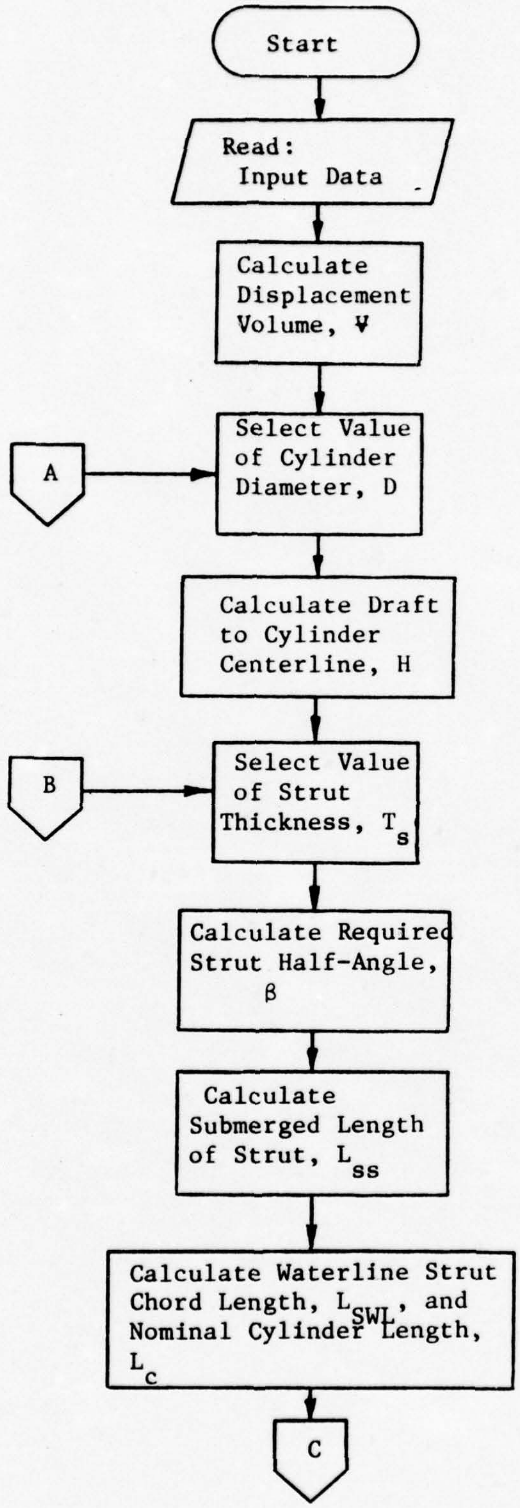

Figure C-3. Flow Chart of Computer Program

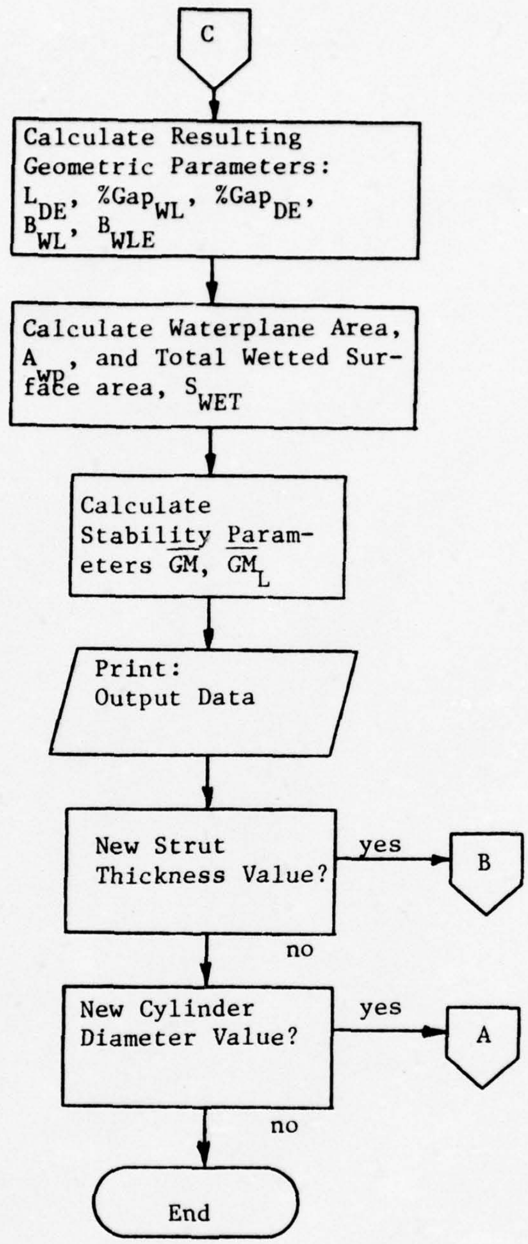

Figure C-3. (continued)

```
C
C     PROGRAM TO FIND MAIN DIMENSIONS OF MONOFORM HULL
C
    1 FORMAT(10X,6F10.6)
    5 FORMAT(13X,"STRUT DATA:"/)
    6 FORMAT(15X,"TS/LSWL = ",F6.4/)
    8 FORMAT(15X,"ZETA = ",F6.4/)
    9 FORMAT(15X,"VBAR = ",F6.4/)
   10 FORMAT(15X,"SBAR = ",F6.4/)
   11 FORMAT(15X,"YBAR = ",F6.4/)
   12 FORMAT(15X,"SCORR = ",F7.5///)
   13 FORMAT(13X,"DISP = ",F5.0," TONS"/)
   14 FORMAT(13X,"F = ",F5.2," FT"/)
   15 FORMAT(13X,"KAPPA = ",F6.4/)
   16 FORMAT(13X,"BEAM,DE = ",F5.1," FT"/)
   17 FORMAT(1H1,//////20X,"* * * * * * * * * * * * * * * * * * *")
   18 FORMAT(20X,"*                                   *")
   19 FORMAT(13X,"H/D = ",F5.3/)
   20 FORMAT(20X,"*  MONOFORM GEOMETRIC ANALYSIS  *")
   21 FORMAT(20X,"* * * * * * * * * * * * * * * * * * *"/////)
   23 FORMAT(13X,"D1 = ",F7.3," FT       DDIA = ",F7.3," FT     KDIA
     1 =",I3/)
   24 FORMAT(13X,"TS1 =",F7.3," FT       DTS = ",F7.3," FT     KTS
     1 =",I3)
   25 FORMAT(13X,"SOLUTION NO.",I3/)
   26 FORMAT(20X,"DIAMETER = ",F7.3," FT     H       =",F7.3," FT")
   27 FORMAT(20X,"BETA = ",F7.3," DEG",7X,"TS      = ",F6.3," FT")
   28 FORMAT(20X,"LSWL = ",F7.3," FT",8X,"BWL     = ",F6.3," FT")
   29 FORMAT(20X,"LC   = ",F7.3," FT",8X,"BWLE    = ",F6.3," FT")
   30 FORMAT(20X,"L    = ",F7.3," FT",8X,"B       = ",F6.3," FT")
   31 FORMAT(20X,"GAP,WL = ",F6.2," %",8X,"GAP,DE = ",F6.2," %")
   32 FORMAT(20X,"GM = ",F7.3," FT")
   33 FORMAT(20X,"GML = ",F7.3," FT")
   34 FORMAT(20X,"SWET = ",F6.1," SQ.FT."//)
   35 FORMAT(1H1,2X,"  "//)
   36 FORMAT(20X,"AREA,WP = ",F6.1," SQ.FT.")
C
C     READ INPUT DATA
C
      READ(5,1)T,ZETA,VBAR,SBAR,YBAR,SCORR
      READ(5,1)DISP,F,CON,BDE,ALPHA
      READ(5,1)D1,DDIA,XKDIA
      READ(5,1)ATS1,DTS,XKTS
C
C     INITIALIZATION
C
      KDIA = XKDIA
      KTS = XKTS
      KSOL = 0
      MKOUNT = 5
```

Figure C-4. Source Program Listing

```
      PI = 3.141593
      V = 35.00 * DISP
C
C     PRINT MAIN PARAMETERS
C
      WRITE(6,17)
      WRITE(6,18)
      WRITE(6,20)
      WRITE(6,18)
      WRITE(6,21)
      WRITE(6,5)
      WRITE(6,6)T
      WRITE(6,8)ZETA
      WRITE(6,9)VBAR
      WRITE(6,10)SBAR
      WRITE(6,11)YBAR
      WRITE(6,12)SCORR
      WRITE(6,13)DISP
      WRITE(6,14)F
      WRITE(6,15)CON
      WRITE(6,16)HDE
      WRITE(6,19)ALPHA
      WRITE(6,23)D1,DDIA,KDIA
      WRITE(6,24)ATS1,DTS,KTS
      WRITE(6,35)
C
C     SELECT CYLINDER DIAMETER VALUE
C
      DO 1000 IDIA = 1,KDIA
      D = D1 + FLOAT(IDIA-1)*DDIA
      H = ALPHA * D
C
C     SELECT STRUT THICKNESS VALUE
C
      DO 1000 ITS = 1,KTS
      ATS = ATS1 + FLOAT(ITS-1)*DTS
      ALS = ATS/T
C
C     CALCULATE REQUIRED STRUT HALF-ANGLE
C
      A1 = HDE
      B1 = -2.0*(H+F)
      C1 = ATS
      G1 = A1*A1 + B1*B1 - C1*C1
      E1 = B1*C1 + A1*SQRT(G1)
      F1 = E1/(A1*A1 + B1*B1)
      BR = ARSIN(F1)
      BETA = BR*180.0/PI
      SB = SIN(BR)
      CB = COS(BR)
      TB = TAN(BR)
```

Figure C-4. (continued)

```
C
C     CALCULATE SUBMERGED STRUT LENGTH
C
        ALSS = H/CB - D*0.50
C
C     CALCULATE NOMINAL CYLINDER LENGTH AND LENGTH AT DECK EDGE
C
        X1 = 4.0*V/(PI*D*D)
        X2 =  16.0*ALS*ALS*ALSS*VBAR/(PI*D*D)
        Y1 = 2.0 *(H-CB*D)
        X3 = ALS*(1.0-ZETA)*(1.0 +2.0*F/Y1)
        ALC = X1 - X2
        ALD = ALC + X3
C
C     CALCULATE RESULTING GEOMETRIC PARAMETERS
C
        PGWL = (ALC/ALS - 1.0 - ZETA)*100.0
        X1 = F*(ZETA-1.0)/(ALSS*CB)
        PGDF  = 100.0*(ALC/ALS -1.0-ZETA + X1)
        BWL = 2.0*H*TB
        BWLF = BWL + ATS/CB
C
C     CALCULATE WATERPLANE AND TOTAL WETTED SURFACE AREAS
C
        SC = SCYL(D,ALS,ALC,SCORR)
        STOT = SW(SC,ALS,ALSS,SBAR)
        AWP = 6.0*ATS*ALS/(3.0*CB)
C
C     CALCULATE METACENTRIC HEIGHTS
C
        GMT = GM(VBAR,ALS,D,V,ALPHA,CB,TB,YBAR,T,CON,F)
        GMLA = GML(VBAR,ALS,D,V,ALPHA,CB,YBAR,T,ALC,ZETA,CON,F)
C
        IF((MKOUNT.LT.4).AND.(ITS.NE.1))GO TO 1002
        MKOUNT = 0
        WRITE(6,35)
 1002   MKOUNT = MKOUNT + 1
        KSOL = KSOL + 1
C
C     WRITE OUTPUT DATA
C
        WRITE(6,25)KSOL
        WRITE(6,26)D,H
        WRITE(6,27)BETA,ATS
        WRITE(6,28)ALS,BWL
        WRITE(6,29)ALC,BWLF
        WRITE(6,30)ALD,BDE
        WRITE(6,31)PGWL,PGDF
        WRITE(6,32)GMT
        WRITE(6,33)GMLA
        WRITE(6,36)AWP
```

Figure C-4. (continued)

```
      WRITE(6,34)STOT
 1000 CONTINUE
      WRITE(6,35)
      STOP
      END


      FUNCTION SCYL(D,ALS,ALC,SCORR)
      PI = 3.141593
      X1 = (SQRT(17.0)/4.0)-0.50
      X1 = X1*PI*D*D
      X2 = PI*D*ALC
      X3 = 4.0*ALS*ALS*SCORR
      SCYL = X1 + X2 - X3
      RETURN
      END


      FUNCTION SW(SC,ALS,ALSS,SBAR)
      SW = SC + 4.0*SBAR*ALS*ALSS
      RETURN
      END


      FUNCTION GM(VBAR,ALS,D,V,ALPHA,CB,TB,YBAR,T,CON,F)
      X1 = (2.0*ALPHA)-CB
      X2 = VBAR*((ALS*D)**2)/V
      X3 = (2.0*ALPHA*YBAR/CB) + 1.0 - YBAR
      Y1 = X1*X2*X3
      Y2 = 4.0*((T*ALS/CB)**3)*ALS/(26.25*V)
      X1 = (ALPHA*TB*D*ALS)**2
      Y3 = X1*8.0*T/(3.0*V*CB)
      Y4 = CON*(F+(ALPHA*D))
      GM = Y1+Y2+Y3-Y4
      RETURN
      END


      FUNCTION GML(VBAR,ALS,D,V,ALPHA,CB,YBAR,T,ALC,ZETA,CUN,F)
      X1 = ((ALS*D)**2)*VBAR/V
      X2 = (2.0*ALPHA)-CB
      X3 = (2.0*ALPHA*YBAR/CB) + 1.0 - YBAR
      Y1 = X1 * X2 * X3
      X1 = ((ALC-(ZETA*ALS))*ALS)**2
      Y2 = X1*2.0*T/(3.0*V*CB)
      Y3 = 2.0*T*(ALS**4)/(15.0*V*CB)
      Y4 = CON*(F+(ALPHA*D))
      GML = Y1 + Y2 + Y3 - Y4
      RETURN
      END
```

Figure C-4. (continued)

Calculation of Strut Parameters

The normalized strut parameters ($\bar{V}$, $\bar{Y}$, $\bar{S}$, $\bar{S}_{CORR}$) are defined in terms of a single strut with unity waterline chord and submerged length, as shown in Figure C-5. For such a strut, the parameters are:

(a) $\bar{V}$ - the volume of the strut

(b) $\bar{S}$ - the lateral surface area of the strut

(c) $\bar{Y}$ - the height of the strut volume's centroid above the base

(d) $\bar{S}_{CORR}$ - the cross-sectional area of the strut, at the base. (This area is to be subtracted from the surface area of the cylinder.)

For non-tapered, lenticular struts (Type A) these parameters can be found from the following expressions.

$$\bar{V} = \bar{S}_{CORR} = 2t/3 \tag{23}$$

$$\bar{Y} = 0.5 \tag{24}$$

$$\bar{S} = \frac{R(1+t^2)}{2t} \sin^{-1}\left[\frac{2t}{1+t^2}\right] \tag{25}$$

Parameter values for Type B struts were determined with the use of a digital computer program, which took into account the change in underwater geometry from lenticular to streamlined cross-section. The normalized parameter values for strut types A and B are listed in Table C-1.

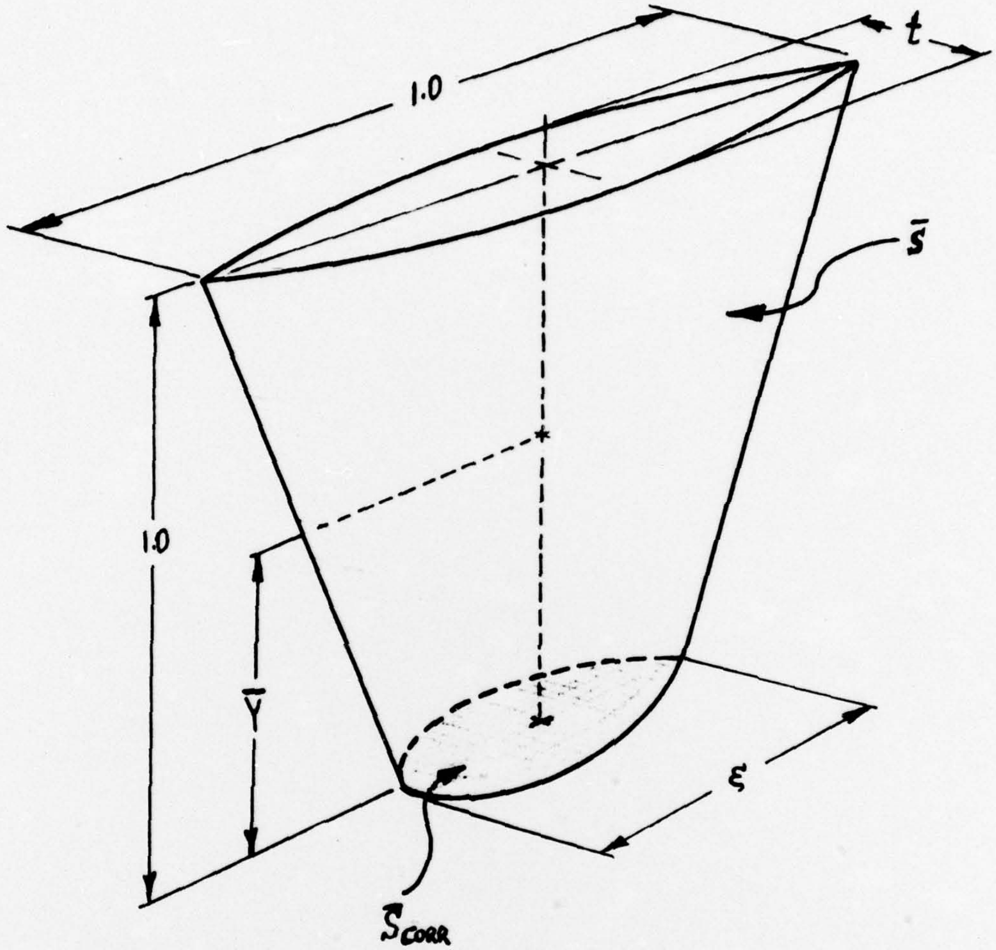

Figure C-5. "Unit Strut" Configuration

Input Data Format

Only four input data cards are required for program operation. The data necessary for each of these cards is described below. All input cards have the same FORMAT (10X, 6F10.6).

Card 1: Strut Parameters

The values for t, ξ, $\overline{V}$, $\overline{S}$, $\overline{Y}$, and $\overline{S}_{CORR}$ of the selected strut geometry are placed in that order on the first card.

Card 2: The values of Δ (long tons), F(ft), κ, B_{DE}(ft), and α are placed in that order on the second card.

Card 3: Cylinder Diameter Parametric Data

The third card is to contain the values of D1, DDIA, and KDIA in that order. D1 is the first value of the cylinder diameter to be employed. DDIA is the value by which the diameter is incremented. KDIA is the integer number of diameters to be used.

Card 4: Strut Thickness Parametric Data.

The values of ATS1, DTS, and KTS are entered on the last data card. ATS1 is the first value of the strut thickness to be used, DTS is is the value by which the strut thickness will be incremented, and KTS is the integer number of values of the strut thickness to be used.

Example of Program Use

The following constraints are chosen for comparison with the SSP.

(i) Δ = 190 long tons

(ii) F = 6.0 ft

(iii) H/D = 1.85

(iv) Strut Type B, t = 0.15, ξ = 0.50

(v) $\kappa = 0.71$

(vi) $B_{DE} = 45.0$ ft

The values of the cylinder diameter and strut thickness to be used are selected as:

$D = 7.4,\ 7.5,\ 7.6$ ft

$T_S = 4.3,\ 4.4,\ 4.5$ ft

From Table C-1, the strut parameters are found to be:

$\overline{V} = 0.07991$

$\overline{Y} = 0.5534$

$\overline{S} = 1.5524$

$\overline{S}_{CORR} = 0.05445$

The desired values of the cylinder diameter and strut thickness indicate that the input parameters are:

D1 = 7.4

DDIA = 0.1

KDIA = 3

ATS1 = 4.3

DTS = 0.1

KTS = 3

The corresponding input data cards are shown in Figure C-6.

The output of the program using the above input data is presented in Figure C-7.

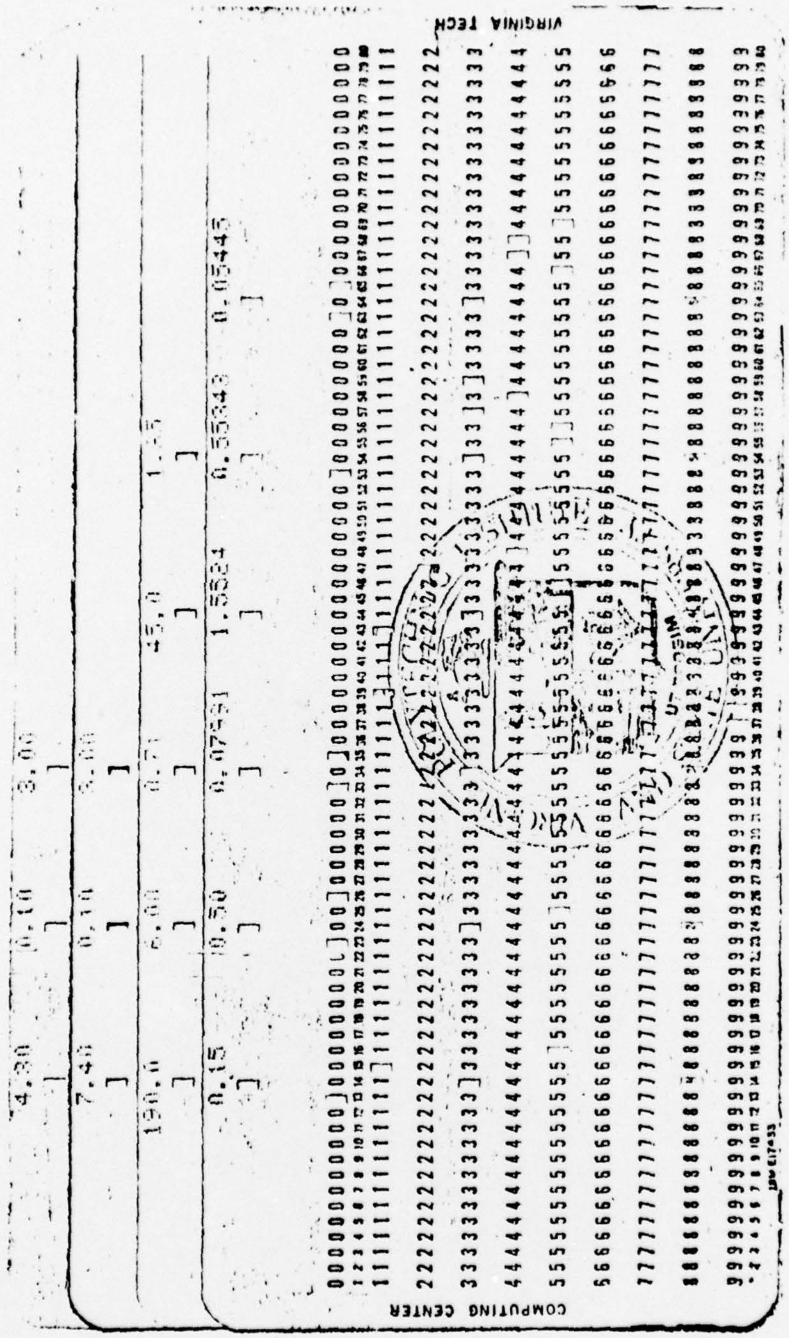

Figure C-6. Input Data Cards

```
* * * * * * * * * * * * * * * * *
*                               *
*  MONOFORM GEOMETRIC ANALYSIS  *
*                               *
* * * * * * * * * * * * * * * * *


STRUT DATA:

  TS/LSWL = 0.1500

  ZETA = 0.5000

  VBAR = 0.0799

  SBAR = 1.5524

  YBAR = 0.5534

  SCORR = 0.05445


DISP =  190. TONS

F =  6.00 FT

KAPPA = 0.7100

BEAM,DF =  45.0 FT

H/D = 1.850

D1 =   7.400 FT     DDIA =   0.100 FT    KDIA        =  3

TS1 =  4.300 FT      DTS =   0.100 FT    KTS         =  3
```

Figure C-7. Typical Program Output

SOLUTION NO. 1

DIAMETER =	7.400 FT	H =	13.690 FT
BETA =	44.687 DEG	TS =	4.300 FT
LSWL =	28.667 FT	BWL =	27.082 FT
LC =	59.615 FT	BWLF =	33.130 FT
L =	84.152 FT	B =	45.000 FT
GAP,WL =	57.96 %	GAP,DF =	30.83 %
GM =	4.291 FT		
GML =	29.894 FT		
AREA,WP =	462.3 SQ.FT.		
SWET =	4067.3 SQ.FT.		

SOLUTION NO. 2

DIAMETER =	7.400 FT	H =	13.690 FT
BETA =	44.591 DEG	TS =	4.400 FT
LSWL =	29.333 FT	BWL =	26.992 FT
LC =	55.349 FT	BWLF =	33.170 FT
L =	80.467 FT	B =	45.000 FT
GAP,WL =	38.69 %	GAP,DF =	11.55 %
GM =	5.036 FT		
GML =	24.837 FT		
AREA,WP =	483.3 SQ.FT.		
SWET =	4016.3 SQ.FT.		

SOLUTION NO. 3

DIAMETER =	7.400 FT	H =	13.690 FT
BETA =	44.495 DEG	TS =	4.500 FT
LSWL =	30.000 FT	BWL =	26.901 FT
LC =	50.997 FT	BWLF =	33.210 FT
L =	76.697 FT	B =	45.000 FT
GAP,WL =	19.99 %	GAP,DF =	-7.16 %
GM =	5.791 FT		
GML =	19.888 FT		
AREA,WP =	504.7 SQ.FT.		
SWET =	3966.8 SQ.FT.		

Figure C-7. (continued)

SOLUTION NO. 4

```
DIAMETER =    7.500 FT      H       = 13.875 FT
BETA =   44.438 DEG         TS      =  4.300 FT
LSWL =   28.667 FT          BWL     = 27.211 FT
LC   =   57.282 FT          BWLE    = 33.233 FT
L    =   81.709 FT          B       = 45.000 FT
GAP,WL =   49.82 %          GAP,DE  =  23.03 %
GM =    4.344 FT
GML =  26.155 FT
AREA,WP =  460.4 SQ.FT.
SWET = 4056.1 SQ.FT.
```

SOLUTION NO. 5

```
DIAMETER =    7.500 FT      H       = 13.875 FT
BETA =   44.342 DEG         TS      =  4.400 FT
LSWL =   29.333 FT          BWL     = 27.120 FT
LC   =   53.092 FT          BWLE    = 33.272 FT
L    =   78.098 FT          B       = 45.000 FT
GAP,WL =   31.00 %          GAP,DE  =   4.19 %
GM =    5.098 FT
GML =  21.461 FT
AREA,WP =  481.2 SQ.FT.
SWET = 4008.1 SQ.FT.
```

SOLUTION NO. 6

```
DIAMETER =    7.500 FT      H       = 13.875 FT
BETA =   44.247 DEG         TS      =  4.500 FT
LSWL =   30.000 FT          BWL     = 27.030 FT
LC   =   48.819 FT          BWLE    = 33.311 FT
L    =   74.404 FT          B       = 45.000 FT
GAP,WL =   12.73 %          GAP,DE  = -14.08 %
GM =    5.861 FT
GML =  16.896 FT
AREA,WP =  502.6 SQ.FT.
SWET = 3957.7 SQ.FT.
```

Figure C-7. (continued)

SOLUTION NO. 7

DIAMETER = 7.600 FT	H = 14.060 FT
BETA = 44.191 DEG	TS = 4.300 FT
LSWL = 28.667 FT	BWL = 27.337 FT
LC = 55.652 FT	BWLE = 33.334 FT
L = 79.373 FT	B = 45.000 FT
GAP,WL = 42.04 %	GAP,DF = 15.58 %
GM = 4.398 FT	
GML = 22.784 FT	
AREA,WP = 458.4 SQ.FT.	
SWET = 4045.9 SQ.FT.	

SOLUTION NO. 8

DIAMETER = 7.600 FT	H = 14.060 FT
BETA = 44.096 DEG	TS = 4.400 FT
LSWL = 29.333 FT	BWL = 27.246 FT
LC = 50.937 FT	BWLE = 33.373 FT
L = 75.834 FT	B = 45.000 FT
GAP,WL = 23.65 %	GAP,DF = -2.83 %
GM = 5.159 FT	
GML = 18.431 FT	
AREA,WP = 479.2 SQ.FT.	
SWET = 3998.9 SQ.FT.	

SOLUTION NO. 9

DIAMETER = 7.600 FT	H = 14.060 FT
BETA = 44.001 DEG	TS = 4.500 FT
LSWL = 30.000 FT	BWL = 27.156 FT
LC = 46.739 FT	BWLE = 33.411 FT
L = 72.212 FT	B = 45.000 FT
GAP,WL = 5.80 %	GAP,DF = -20.69 %
GM = 5.932 FT	
GML = 14.229 FT	
AREA,WP = 500.5 SQ.FT.	
SWET = 3949.5 SQ.FT.	

Figure C-7. (continued)

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